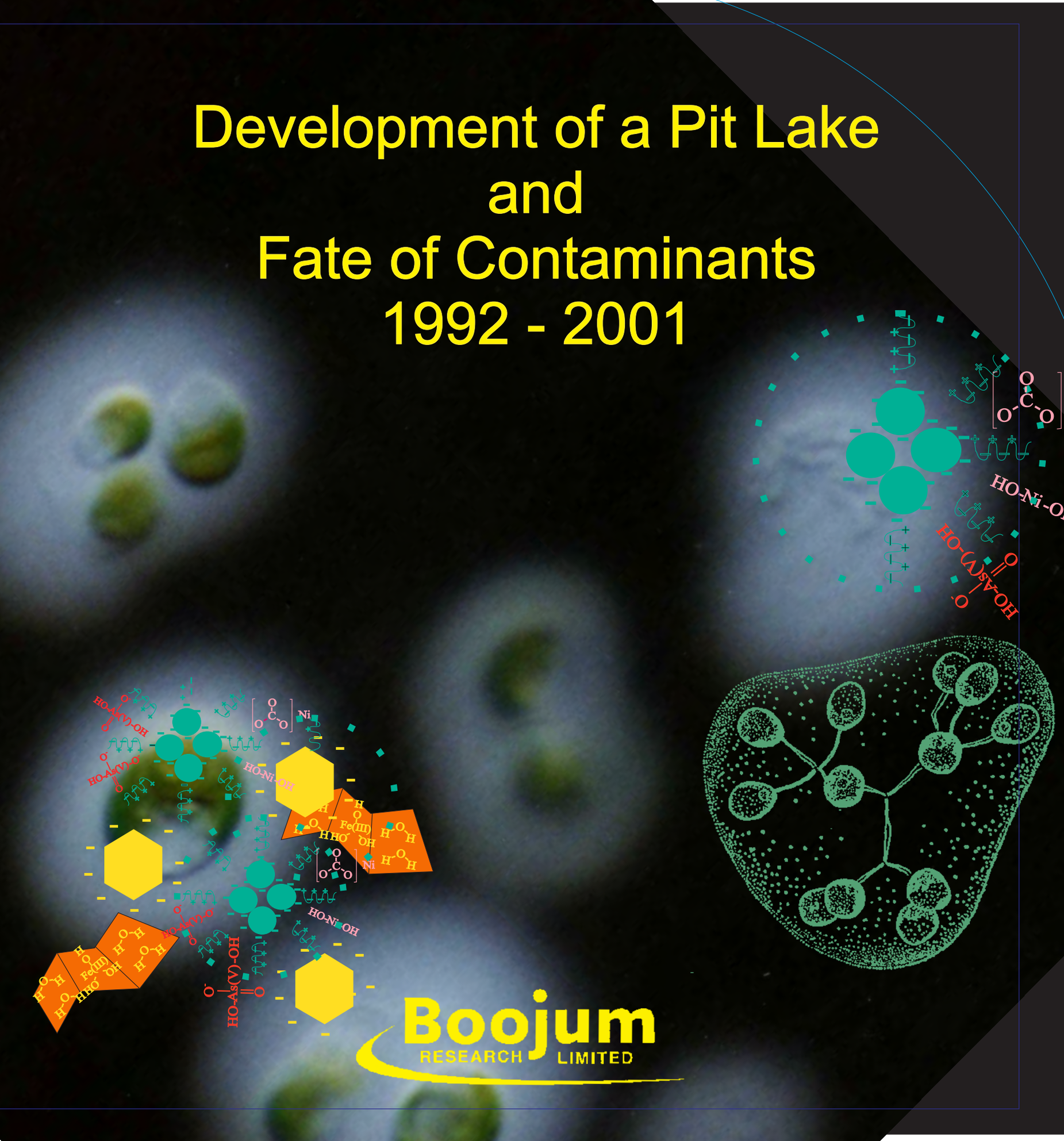
Development of a Pit Lake and Fate of Contaminants 1992 - 2001



Boojum RESEARCH LIMITED

Development of a Pit Lake
And
Fate of Contaminants
1992-2001

July 2002

EXECUTIVE SUMMARY

The B-Zone pit was intentionally flooded with water from the adjacent Collins Bay in the winter of 1991/1992. Evidence that contaminants are not being released from the pit walls to the water column and the processes responsible for improvements observed in pit water quality are described. Limnological data gathered for a decade support this finding.

Since 1991, the water quality in the pit lake has been rigorously and regularly monitored with close attention paid to the primary productivity (phytoplankton quantification) of the flooded pit. An elemental mass balance has been calculated, based upon materials acquired by suspending sedimentation traps at various depths, and bottom sediment sampling. By 1997, this was indicating that natural cleansing processes were effectively reducing both Ni and As, the contaminants of concern, in the water.

The striking singularity in the data showed that concentrations of Ni increased every spring after ice break-up. It was initially believed that Ni was being released by the decomposition of suspended organic matter and recycling. However, by 1998 the dynamics of the lake were well understood and it seemed apparent that the only explanation could be an external source of Ni. That source, a mineralized perimeter road, was identified and in 2001 was eliminated. Since then, the concentrations of Ni in the water column have no longer increased seasonally. The steady state of contaminants in the lake water, and its sediments, provides assurance that no new contaminants are entering the pit.

Active contaminant removal by pumping of water from the pit lake to maintain water level was also evaluated. This provided evidence against one of the last arguments that dilution from clean water entering the pit lake was leading to the reductions in As and Ni concentrations and not the natural water cleansing processes. If necessary, these processes could be enhanced further by fertilization. A final decommissioning strategy for the B-Zone Pit has not yet been determined.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF SCHEMATICS

LIST OF APPENDICES

1.0 Introduction and Background

Pit lakes, which are frequently associated with water quality problems such as low pH, high metal concentrations, and high suspended and dissolved solids have recently been the focus of much research (Levy et al., 1996; Geller et al., 1998; Doyle et al., 1995; Davis and Ashenberg, 1989). One such lake was created in 1991 by the flooding of the former B-Zone Pit Uranium Mine, part of Cameco Corporation's Rabbit Lake Operation in Northern Saskatchewan. In the recognition that this had created an invaluable opportunity to research not only the contaminants associated with pit lakes, but the natural processes which mediate them, Boojum Research Ltd and Cameco Corporation launched an ambitious, long-term study that was to last almost a decade. The work was jointly funded by CAMECO and by CANMET through its Biotechnology Strategy Program.

As expected the five million m^3 of water that were allowed to flood the pit were quickly contaminated by elevated concentrations of arsenic, nickel and suspended solids. However, within a year reductions of arsenic and TSS were noted and by 2001, despite setbacks, Ni concentrations remained the same seasonally, until the discovery and elimination of an external source. Many reports and publications have been produced and several publications are forthcoming.

This report summarizes data compiled up to 2001 on the limnology, the water quality, and the sedimentation of particulate matter in the B-Zone Pit Lake. All related work is listed in Appendix 1. The pathway of the contaminants As and Ni from the water to the sediments is summarized with a mass balance, describing the natural water cleansing process.

1.1 Understanding contaminant transport: Collecting the evidence 1993 to 1996

The reduction of As and Ni in the B-Zone Pit Lake is controlled by three factors; primary productivity, stratification, and particle formation. Throughout the summer, the stratification of the lake supports an explosion of algae in the photic zone near the surface. The mucilage agglomerate particulate matter containing contaminants. These eventually become large enough to settle, initially to the thermocline and then - primarily in the winter as the strata break down - to the sediments below.

Primary productivity began in the lake with the arrival of *Dictyosphaerium spp a* weedy mucilage-forming algae adapted to the low light conditions caused by the high initial loading of suspended solids; as the clarity of the lake increased, and available nutrients decreased *Dictyosphaerium* gave way to successor species. The accumulation of Ni and As by the algal biomass led to reductions in the concentrations of Ni and As in the surface water. In the case of As, the reduction was carried over from to year, leading to a significant, long term improvement. But Ni concentrations after the turnover were only marginally lower than those at the beginning of the year. This seasonal pattern, or cycling of nickel, was attributed to its release from decomposing biomass at or below the thermocline; oxygen concentrations and redox values confirmed that, in fact, biomass was breaking down at the thermocline, while increases in TOC concentrations provided evidence of heterotrophic microbial activity. (see Appendix 1 for reports).

There was no doubt that the organic materials were capturing Ni. Granulometric analysis of material collected in the sedimentation traps determined that up to 80% of the particles in the B-Zone pit are smaller than 1 um, which suggest that they are too small to sediment to the bottom, but they remain suspended. Fractionation of particles by filtration ranging from filter sizes of 0.1 um to 1.0 um indicated that indeed nickel occurs in particulate form bound to or aggregated by biological material. This was also confirmed by the surface sedimentation trap material. Iron was a dominant constituent of the particulate matter throughout the pit, covering the entire size range of particles.

The extremely small size of the particles provoked more detailed investigations into the locations of adsorption sites on the particulate matter collected in the sedimentation traps. Examinations of the material with SEM (Scanning Electron microscopy) and EDXRF (Energy Dispersive X-Ray Fluorescence spectrometry) confirmed that the contaminants were associated with the very small particles. Investigations with SIMS (Secondary Ion Mass Spectroscopy) indicated that the surface layer of the particles, containing the contaminants, becomes thinner as they drift deeper in the pit.

These findings correspond with the proposed decrease in biological aggregate material and the onset of decomposition of the bio-molecules. In addition, the elemental composition of the sedimentation trap material, along with sequential extractions performed on the collected particles (Lowson 1997) confirmed the same trends. Higher concentrations of organic phosphate in the surface samples further supported the role of the biological component in the particulate formations and the transport mechanism.

The dominant geochemical form of arsenic in the pit water is arsenate in the ionic state with a two minus charge, while nickel is present mainly as a nickel carbonate and as nickel hydroxide, both with very weak surface charges. Algal cell walls are negatively charged. Experiments using negatively charged bentonite, simulating algae cell walls, reproduced this agglomeration behaviour. If nickel was present in the lake water as a free Ni^{2+} ion, not as the predicted geochemical form of nickel hydroxide, it would have adhered to the bentonite. But, as expected, it did not and neither did arsenic. This confirmed both the geochemical state of the contaminants and the fact that the agglomeration of contaminants is driven by surface charge. The work was summarized in detail in the May, 1997 *report B-Zone Pit Limnology 1993-1996 and the Fate of Arsenic and Nickel, April 1997*.

Schematic 1a depicts the particle agglomerations and the natural water cleansing processes taking place in the pit lake. The size of the individual components, as given by Buffle (1995) is reproduced in Schematic 1b. In order to settle, a particle needs to be at least one micrometer in size, and thus the organic cells walls or the organic compounds with their surface charges serve to aggregate smaller particles into larger particles, which can reach the bottom of the pit.

The understanding of the pit dynamics, based on investigations carried out from 1993 to 1996, and reported in detail in May 1997 (B-zone Pit Limnology, 1993-1996) was that biological removal mechanisms were less permanent than had been hoped and expected at least in the case of Ni. That conclusion, however, was based on the assumption that the pit was a closed system, unaffected by any external source of contamination.

1.2 The proof is in the sediment 1997- 1998

Estimates based on a detailed analysis of the material from sedimentation traps, suspended in the water column at depths of 2, 12, 22 and 32 m, and concluded that by 1997, 2 tonnes of arsenic had accumulated in the sediments on the bottom. This was consistent with concentrations of As found in two samples of sediment from the pit bottom, taken in 1997, with an Ekman grab sampler. Similarly, the estimated and actual concentrations of other elements including iron, aluminum and uranium, were in agreement

But, again, Ni was an anomaly. The working hypothesis for the continued presence of Ni of in the water column was that it was being captured but released by the breakdown of phytoplankton above the thermocline. It followed that there would be very little Ni in the lake sediments, which were created entirely by the deposition of previously suspended solids. In fact, the two sediment samples revealed concentrations of Ni which agreed with the expected mass estimated up to 1999. Moreover, visual observations of the sediment samples revealed a jelly like layer covering the sediment surface, confirming that a portion of the biomass reaches the bottom without significant decay.

The assumption that the pit was a closed system held true for As and other elements but clearly did not apply to Ni. As reported to regulatory agencies in February 1999 (*The Fate of Arsenic and Nickel: The proof is in the sediment*) the mass balance of Ni could be rationalized only by the assumption of an external source.

In 1999, more samples were collected providing a more comprehensive understanding of the uppermost 7 centimeters of the bottom sediment. These again substantiated the

accountability for the observed elements among them Fe (556 g/m$^{2\ measured}$ vs. 555 g/m^2 predicted) and As (30 g/m^2 measured vs. 42 g/m^2 predicted). And the readings for Ni were in perfect agreement; 17 g/m^2 in both the projected and measured. But this left no margin to account for the Ni that was believed to have been recycling back into the water column by the decomposition of the biomass suspended at the thermocline. The nickel in the water therefore had to be derived from an external source. (Details about these samples and the mass balance of the lake are given in Section 6.0).

2.0 The 'blue road' as the external Ni source

In 1997, as part of an investigation into above-background gamma radiation, a turquoise or bluish coloration was noted on the surface of a perimeter road southwest of the pit. In 1999, with the recognition that Ni was being renewed in the pit lake, the coloration was again noted, not only on the road but on erosion fans leading from it and on its banks. If these water-soluble, blue evaporites contained nickel, they would explain the seasonal pattern of the Ni concentrations in the pit lake. Generally, throughout the study the lake had been sampled four times a year; the highest concentrations of contaminants were reported in the spring, reductions in June and July and an increase after the heavy rains in August and September and the beginning of the thermocline breakdown.

The evaporites suggested a scenario that closely fit the observed data; the evaporites form and remain on the road in the generally dry summer while the biomass in the lake experiences its highest rate of growth, and accumulation of aggregates bringing Ni to its lowest annual concentration; in the fall, heavy rains carry the evaporites to the lake just as its biomass, and its bio-polishing capacity subsides. Sampling intervals of the lake were too infrequent to precisely relate limnological changes to rain-related inputs, but nonetheless strongly implicated the road with the recurrent levels of Ni.

With the identification of a possible external, mobile Ni source the role of the biomass as an important transport mechanism of Ni and As, (Schematic 1a), became more prominent than previously believed. The Ni in the sediment was indeed the result of sedimentation process of the biological aggregates formed, large enough to reach the bottom without significant decomposition and release of Ni.

2.1 The characteristics of the 'blue road'

The potential of the blue road as a source of Ni was evaluated during summer field trips by Boojum Research in 1999 and 2000. A series of water and solid samples were collected during a rainfall from puddles in the blue areas**.** In addition, during a rainfall event, a series of water and solid samples were collected from puddles in the blue area**.** The locations at which run-off from rain enters the pit lake were easily identified by the presence of filamentous algal and iron hydroxide staining. The run-off samples contained concentrations of Ni as high as 44 mg/L Ni while a filtrate prepared from surface evaporite material produced concentrations of 1,530 mg/L of Ni. Concentrations of Ni in ground water seepages were generally lower, ranging from 0.036 mg/L to 1.14 mg/L while As ranged from 0.03 mg/L to 1.7 mg/L (Table 1a, Appendix 5). The sampling locations are reported in Table 1a and 1b and on Map 1 in Appendix 5)

Evaporite samples gathered in 1999 and 2000 consisted largely of Ni with concentrations ranging as high as 19%; As was also present but at considerably lower concentrations of < 0.01 % to 0.2 % (Table 1b, Appendix 5). These were much higher than the concentrations found in rock blooms sampled in the B-Zone waste rock pile in 1993 and 1997 (0.1 % As and 0.09 % Ni (N=18) with a maximum concentration in the entire sample set of 1 % As and 0.7 % Ni. This was not surprising since evaporates are formed through the wicking of pore-water out of weathered, highly-mineralized rock. In comparison, waste rock as a whole rock sample typically contains lower concentrations of both As (0.007 %) and Ni (0.009 %). (Appendix 5, Section 4 Table 1b).

The weathering of rocks in the perimeter road appeared to preferentially liberate Ni. Liberated arsenic would have precipitated within the gravel pore-water with Fe^{+3} also liberated by weathering. The predominant contaminant in samples gathered during a rainstorm was Ni, indicating that the perimeter road preferentially released Ni. If As had been liberated it would have precipitated with liberated Fe^{+3} and would have not reached the pit lake.

The results of a further investigation, including a detailed description of the distribution of the evaporites and ground water seepage conditions is contained in the 2000 report *B-Zone*

Perimeter Road, by P. Landine of Cameco. A second report in 2001 *B-Zone pit perimeter road; Follow up Investigation* has been submitted to the regulatory agencies. Both reports are included in Appendix 5.

In the 2001 report, P. Landine provided estimates of Ni load to the B-Zone pit based on simulations of a run-off event. He concluded that about 11 kg entered the pit during a single rain event. This would result in a seasonal addition of as much as 100 kg of Ni. These run-off estimates are within the range of the mass of Ni contained in the 0 - 5 m layer of pit lake water, a layer containing about 1 million m^3 of sediment and about 245 kg to 285 kg Ni, using concentrations measured in 1995-1998 when the lake was ice covered (Table 7a, Appendix 5).

As Ni appears to be the most mobile element and no increases in other elements are noted in the pit, the "blue road" is the most likely source of Ni to the pit-lake. As per a recommendation by P. Landine, approximately 7,950 m^3 of waste rock were removed from the road by October, 2001.

2.2 Are there other contaminant sources - the pit walls?

A decade of research has yielded a clear understanding of the dynamics of B-Zone Pit Lake and its contaminants. When the pit was flooded in 1991, it was expected that a significant contaminant load would be generated, posing a threat to the water quality of Collins Bay. Accordingly, regulators requested the implementation of measures to assure the stability of the dyke that separated the pit lake from Wollaston Lake. Geo-technical inspections of the dyke have been carried out regularly since that time. Since 1999, the head differential between the water bodies has been reduced twice annually by pumping pit lake water to the treatment plant. This pumping removes Ni and Arsenic as well as phytoplankton and TSS from the surface water layer. A submersible pump removes water at an average rate of approximately 1000 L/min, after ice melt and prior to freeze up.

It has long been hoped that when the water quality of the pit lake is acceptable, the dyke can be breached and the pit-lake rejoined with Wollaston Lake. With the complete understanding of the sources and sinks of contaminants in the B-Zone Pit Lake, and with the "Blue Road" eliminated as a source of Ni, it is now clear that the pit walls are not generating contaminants. If the continued monitoring in 2001-2004 confirms the success of the clean-up of the road, there would seem to be little reason to further postpone the breaching of the abutment.

The dramatic, seasonal reductions of Ni, seen in the past, are unlikely to occur again since nutrient limitation will restrict algal growth in the early summer. Furthermore, when the dyke is breached the thermocline in the pit lake will become similar to that in Collins Bay, that is easily destroyed by strong winds. Sawchyn (1973) has written of Wollaston Lake that:

> "Evidence of thermal stratification was found at all stations on several occasions during the summer. Thermal stratification never became permanently established as it commonly does in the lakes of the southern part of the province. Generally, a thermocline began developing during a period of calm, warm weather but disappeared during a wind storm as in the weeks preceding July 6, July 20th and August 3 (Figures 1-8). As a result, it seldom lasted through more than two consecutive weeks".

Sawchyn's measurements of the Wollaston Lake thermocline were carried out weekly measurements, as compared to 4 measurements during one year in the pit lake. The wind effect on the pit lake will be limited however, since only the top portion of the dyke or, better, the abutment will be breached, allowing less mixing. The maximum reported depth of Collins Bay is 25 m, whereas the pit is 45 m deep with a present thermocline at a maximum of 10 m. In other words, the deep, cold water in the pit lake will not mix with the water from Collins Bay, as cold water does not move upward.

3.0 The pit chemistry and its thermocline 1997 to 2001

As the B-zone pit lake is a closed system there is no reason to suspect that its patterns of stratification and associated chemistry should change other than by the discussed processes. To provide a perspective over a larger time span, the early years are compared to the most recent four years. Although pumping has taken place for the last three years, it is unlikely to have affected the thermocline

Appendix 2 provides depth profiles for temperature (Figure 1a to 1d) for 1997-2001. No thermocline was evident in June, 1999, but by July, 1999 was present to a depth of about 5 m increasing 7 m prior to winter. The same pattern was noted in 2000 and 2001 where a very deep thermocline formed to a depth of 17 m by the end of 2001.

Oxygen profiles (Figure 2a to 2d, Appendix 2) suggest oxygen is super-saturated in the surface water, particularly in 2000 and 2001. The reason for this is not clear but may be due to faulty readings of the Hydrolab. At a water temperature of 5 ^{0} C, the surface water is at equilibrium with the atmosphere at 1310 feet (397m), and saturated oxygen concentrations are 11 mg/L, less than recorded in the pit water in 2000 and 2001.

Redox potential (Eh) readings measured below the ice in 1999 were extremely low but increased both during the ice free season and from year to year, by 100 to 200 mV (Figure 3a to 3d, Appendix 2). In the years 1993 to 1996, the pattern was consistent, exhibiting a decrease after ice breakup in Eh values of about 100 mV and remaining relatively constant throughout the rest of the season. There is no obvious mechanism that explains the induction of these seasonal changes, other than malfunction of the instrument. For example, in Figure 3b (Appendix 2) the June/July, 2000 readings at various depths, reported values around 350 mV, whereas by August of the same year the readings were between 0 to 50 mV (Figure 3c, Appendix 2) only to increase back to around 250 mV by October, 2000.

The pH values also exhibit large changes, when compared to 1993-1996. After ice breakup,

the pH in the surface water increased generally by about 0.5 to 1.0 units, but was stable below the thermocline at 6.5 to 7. By the end of 1999 the pH throughout the pit was around 8; it dropped after the spring melt in 2000 to 6.7; climbed to 8.2 by August 2000, and dropped again to 7.4 by August 2001. In September 2001 the pH above the thermocline was 6.6 and dropped to 5.6 at 15 m. By October 2001 the surface water was acidic, with pH ranging between 3.5 to 4.5, increasing with depth to a value slightly above 7 (Figure 4 a to 4d, Appendix 2). If such dramatic changes in pH values and Eh values are indeed taking place, there should be signs of it in the pit chemistry, as both dissolution and precipitation reactions would be taking place. This is not the case. The absence of changes in conductivity, given the large variations in pH and Eh, reported in the 2001 report (Figure 5a to 5d Appendix 2) indicate a malfunction of the Hydrolab.

Beneath the ice, in the years 1993-1996, the bottom of the lake had generally higher conductivities, between 60 and 90 µS/cm. Since 1998, conductivity values have not increased with depth below the ice but have remained slightly below 90 µS/cm. (Figure 5a, Appendix 2). The values generally remained the same throughout the pit, season to season, with minor changes in 1997-2001 (Figure 5b to 5d, Appendix 2). Figure 6a to 6d (Appendix 2) provides sodium concentrations. They show no significant variations either by depth or by year. Potassium values (Figure 7a to 7 d, Appendix 2) have remained around 2 mg/L. In Figure 8a to 8d (Appendix 2) magnesium concentrations show a minimal increase of about 1 mg/L by the year 2001.

Calcium concentration throughout the pit increased from about 5.5 mg/L in 1993 to 7.5 mg/L in 2001 (Figure 9a to 9d, Appendix 2). In the same period sulphate increased from about 10 mg/L to 14 mg/L (Figure 10a to 10d, Appendix 2). Figure 11a to 11d (Appendix 2) plots bicarbonate concentrations for 1997-2001. The concentrations of this parameter have also increased since 1991, from an initial value of around 13mg/L throughout the pit in all seasons to values of about 30 mg/L or higher by 2001.

If we consider the pH increases in the pit, excluding the low surface values obtained in 2001, the bicarbonate increases could be explained by the carbonate dissolution system

described by Stumm and Morgan (1995). From the chemical perspective, a pit lake is an open system, where gaseous exchange of CO_2 and NH_4 can take place from the water to the atmosphere. In fact, Cameco staff report that during the winter, ice mounds which might be the result of degassing often form on the lake.

It would be possible to predict changes in the lake given a certain level of primary productivity. This would support the interpretation that the noted pH and bicarbonate increases and concurrent Eh decreases are the result of biological activity. However, phytoplankton productivity values would be required for such calculations and those are no longer being collected. Instead, nutrient concentrations between 1997 and 2001 are examined as an indicator of biological activity.

Figure 12 (Appendix 2) provides phosphate concentrations. These have been low since 1999 and by 2000 were either close to or at the analytical detection limit. However it should be noted, that even such low concentrations can support biological activity. Figure 13 (Appendix 2) shows that at the end of the 2001 growing season, the changes in concentrations of NO_3, which increase with depth, were particularly pronounced suggesting some microbial activity. Ammonia concentrations in the pit lake which were generally low (below or at 0.05 mg/L) in 1993-1996, (page 32 of the 1997 report) were at or above 0.1 mg/L by the year 2001. Again, the highest readings were obtained at the end of the summer (Figure 14, Appendix 2).

Total organic carbon concentrations (TOC) changed little up to 2000 (Figure 15, Appendix 2). A slight increase was noted in the fall of 2000 to values of 6 mg/L which may reflect an opportunistic fall algal bloom, quite likely due to the changing nutrient conditions. Finally, TSS which remained at or below 5 mg/L before 1996 (Figure 16, Appendix 2), dropped substantially by 1998 to around 2 mg/L or less throughout the pit.

A review of the nutrient status of the pit lake and its chemical and physical conditions, based on data in Appendix 2, suggests that some chemical parameters such as Eh, pH and

bicarbonate have changed dramatically since the pit was flooded. Nutrient status is a product of the conversions of nitrogen compounds and an associated depletion of phosphate and nitrate. Recent conditions are quite different from those that prevailed when the lake was developed, when biological polishing was first proposed as a means of contaminant removal. Data generated prior to 1998 strongly substantiates the relationship between the pit lake chemistry and its algal population (Kalin, et al. 2000). It is difficult to predict, based on available data, the effect of recent decreases in biological activities on water quality.

4.0 Nutrient stressed biology

The dominance of *Dictyosphaerium* spp in the early years of the B-Zone Pit Lake, when light penetration was low and nutrients were abundant has long since ended. Table 1 provides the biomass of this species in mg/L. The number of cells were counted and then converted into a biomass concentration; for example, in August 1995 a biomass of 41.30 mg/L represented 3.37×10^{8} cells per liter. By 1999 this had declined to 0.00271 mg/L or 22,000 cells per liter. Large fluctuations in cell counts reflect that algal populations grow and decline rapidly. A total absence of *Dictyosphaerium* species by September 1998 at all depths meant that the water chemistry no longer suited this species.

From 1996 to 1991, total biomass in the lake declined gradually at 32 m to 42 m.; an algal bloom was noted after the 1999 spring melt but did not produce biomass on the scale seen in previous years (Figure 1). With diminishing nutrients, other species were expected to colonize the pit lake. Figure 2 provides comparable density data for the years 1995, 1996 and 1999 plotted by algal group, by depth (shallow to deep), and by season, i.e. April when the pit is ice-covered and in June or August, the growing season.

From 1992 to 1996, the Chlorophytes were the overwhelmingly dominant algal group; they remained dominant until 1999 but by then were sharing the lake with other species, including Euglenophyceae, commonly found in more acidic water, and Cyanobacteria which does well when nitrogen is the limiting factor. Desmids have never been found in the pit lake.

4.1 Nutrient conversions as indicators of biological activity

Nutrient changes in the pit have brought about an increase in bio-diversity but a decrease in total biomass leading to a reduction in available biological agglomeration material. Hence, lower reductions in Ni can be expected.

Table 2a to 2c presents the average concentrations of nutrients above and below the thermocline for the years 1999 to 2001 respectively. In the absence of quantitative or qualitative values for phytoplankton for the years 2000 and 2001, TKN or Kiehldal nitrogen readings for 2001 may serve as an indicator for growth. As TKN values represent total organic nitrogen, they are indicative of biological activity.

The seasonal dynamics of nitrogen compounds above and below the thermocline were discussed in the 1997 report. By the end of 1997, nitrate limitations in the pit lake were restricting the rate of growth of the biomass. Some consideration was given to restoring nitrate levels to pre-1995 levels (0.4 mg/L) to prove the role of biomass and Ni removal in the surface water. The idea was rejected on the grounds that fertilization might interfere with As removal. As a result, in 1997, the biomass was allowed to starve which led to the removal of less Ni from the surface water during the summer.

As photosynthesizing activity occurs mostly near the surface, comparisons to regions below the thermocline are useful. To generate nitrogen compound values for all depths, including those for which no measurements are available, values are based on averages obtained from adjoining depths. As the growing season progresses, algal and microbial activity bring about changes in nitrogen compounds. Changes in values and the associated transformation are given for completeness in Appendix 2 for the years 1995-1998.

Given that the semi-quantitative assessment of the phytoplankton indicates a greater variety of species (Figure 2) with a lower biomass (Figure 1) it is possible to interpret, in the absence of phytoplankton data for the later years, the TKN values. One could make the assumptions that TKN values should be similar for the values reported for 1999-2001, if no major biomass change has taken place. However in October 1999 the value of TKN above the thermocline of 0.27 mg/L and an average value below it of 0.16 mg/L, about half of the nitrogen generated at the surface (Table 2a) suggesting that growth is still taking place. At the end of the 1999 growing season when the thermocline breaks down, the TKN values along with NO_3 concentrations change from 0.09 mg/L at the surface to 0.4 mg/L below the thermocline. The average ammonia concentrations at the surface were 0.09 mg/L with little

change at the bottom 0.11 mg/L. These concentration changes represent true conversions from very low values of one nitrogen compound, to concentrations well above the detection limits of another nitrogen compound.

TKN values were not recorded in 2000 (Table 2b). By August, the end of the growing season, NO_3 just above the thermocline decreased to 0.01 mg/L and below it to 0.06 mg/L. Nitrate concentrations were dramatically reduced from the previous year, whereas ammonia concentrations had increased to 0.05 mg/L above and below the thermocline. As the thermocline beaks down and the ice forms, ammonia concentrations increase and NO_3 decreases.

The year 2000 provides a further example of the conversions of nitrogen compounds discussed above (Table 2b). Ammonia concentrations decreased throughout 2000, from an average value of 0.14 mg/L underneath the ice to a value of 0.07 mg/L by August. The higher values in the spring are reflected in October 1999 below the thermocline and are likely related to winter turnover. Unfortunately in 2000, no TKN values were measured (Table 2b). Below the ice (Oct 2000 - Apr 2001), ammonia concentrations did not increase as they had in the previous year, remaining at around 0.06 mg/L in April 2001 (Table 2c). The TKN value in 2001 averaged 0.15 mg/L, similar to the value below the thermocline in 1999 when ammonia concentrations were nearly twice as high. Throughout 2001, TKN values increased at the end of the growing season, doubling from those beneath the ice, to 0.24 mg/L above the thermocline and 0.23 mg/L below it. This suggests biological activity in 2001, as the TKN value is even higher than in 1999, at the end of the year.

By 2001 phosphate concentrations remained at or slightly above the detection limit of 0.03. Nitrate was not determined but ammonia concentrations continued to decline (Table 2c). At the beginning of the year TKN values at the surface under the ice were unchanged from those at end of the 1999 growing season. They remained low until fall 2001 when they increased to 0.24 mg/L above the thermocline and 0.23 mg/L below it, probably due to an algal bloom. This might have resulted in a concurrent increase in ammonia in August 2001, due to algal decomposition. These changes suggest strong microbial activity with aerobic respiration increasing the ammonia concentration which, in turn, is associated with

decreases in pH and Eh depressions (Stumm and Morgan 1995, chapter 8.5 and 4.5).

Photosynthesis and the respiration of the diminishing algal population interact with the microbial processes of nitrification and de-nitrification affecting the chemistry of the pit lake in keeping with equations defined by Stumm and Morgan (1995):

Nitrification:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$$ Alkalinity decrease

Denitrification:

$$5CH_2O + 4NO_3^- + 4H^+ \rightarrow 5CO_2 + 2N_2 + 7H_2O$$ Alkalinity increase

Photosynthesis with nitrate uptake:

$$106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+ \rightarrow \{C_{106}H_{263}O_{110}N_{16}P\} + 138O_2$$

Alkalinity increase

Photosynthesis with ammonium uptake:

$$106CO_2 + 16NH_4^+ + HPO_4^{2-} + 122H_2O \rightarrow \{C_{106}H_{263}O_{110}N_{16}P\} + 138O_2 + 14H^+$$

Alkalinity decrease

The consumption of nitrate and phosphate during photosynthesis would increase the pH as the reaction consumes 18 H^+ to make biomass. But if photosynthesis uses ammonium-N, the reaction will produce 14 H^+, reducing the pH. The low nitrate concentrations (Figure 13, Appendix 2) coupled to high pH values in the surface waters (Figure 4a to 4d, Appendix 2) in 1996 and 1997 suggests algal growth supported by uptake of nitrate. In 2000 and 2001, the relatively low pH values and relatively high ammonium-N to nitrate ratio (Table 2a, 2b and Appendix 2, Figures 13,14) are indicative of low rates of photosynthesis limited by the low phosphate concentrations and an increase in nitrification which would lower pH.

From the perspective of biological polishing, the available data indicates that since 1999, the algal biomass has been in decline as more microbial activity has begun to prevail. No other explanation can account for the seasonal changes with depth of the nitrogen

5.0 Active and Passive contaminant removal in the pit lake: 1999-2001

From 1991 when the pit lake was created until 1998 no contaminants have left it except by processes of natural removal. Beginning in 1999 the pit has been pumped twice a year to control water levels, after ice melt and in the fall, seasons associated with the algal blooms. The total contaminants removed by both pumping and by natural means should result in an increased rate of water quality improvement.

It is assumed, for the purpose of these estimates, that the year to year contribution of Ni from the perimeter road was relatively constant, along with the contributions of atmospheric precipitation and any potential clean ground water contributions. It is further assumed that the contributions of Ni form the weathering and evaporative wicking processes which led to the formation of the evaporites are constant from year to year.

If all these assumptions are holding, it is reasonable to assess the reductions in concentration of As (Table 3a) and for Ni (Table 3b) are not due to dilution and indeed due to removal of water containing the metals. These reductions are calculated for the years 1999, 2000 and 2001, with the assumption that pumping was the sole means of reduction. As the pumping started just after ice melt, spring concentrations are used as the starting point for the pit. In 1999, the first year of pumping, 159,371 m^3 was drawn from a depth of 0 to 5 m; in the second year of pumping about 109,514 m^3 were removed and 84,829 m^3 was removed in 2001. Given that the 0 to 5 m. layer of the lake contains about 1 million m^3 these were relatively small amounts.

The 0-5 m layer of water would have contained 52 kg of As in 1999, 28 kg in 2000 and 23 kg in 2001 (Table 3a). After pumping the total mass of As remaining in the layer would have been 44 kg (52 kg - 8.3 kg) in 1999, 25 kg in 2000 and 21 kg in 2001, converting this mass back to concentrations results in the projected concentrations of 0.044, 0.025 and 0.021 mg/L for the respective years 1999, 2000 and 2001. The measured concentrations are, in fact, much lower for each year. The additional removal was, most likely, the result of the natural removal process.

Projections are made for Ni removal and associated changes in Table 3b. The projected

and measured concentrations generally are in agreement. No increases are evident, as is normally the case in spring. The measured concentration in the spring of 2000 was higher than projected, but agreed well with 2001. These evaluations, using the removal of contaminants by pumping, support the accuracy of the mass balance of the contaminants in the pit lake. It also confirms that dilution does not lead to the reductions.

Figure 3a, 3b 3c and 3d provides 1992 to 2001 As concentrations, beneath the ice from March to May; Figure 3b for the start of the growing season in June and July, Figure 3c before the breakdown of the thermocline in (August to September and Figure 3d for the end of growing season prior to ice formation in October. It is evident that As concentrations dropped each year by about 0.1 mg/L gradually decreasing to the lowest level in 2001.

In Figure 4a to 4d, the same grouping is used for Ni concentrations plotted with depth from 1992 to 2001. Here the seasonal decreases are about 0.05 mg/L with the lowest concentrations reported in the summer of 1992 then increasing gradually each year in spite of seasonal fluctuations ranging from 0.2 to 0.3 mg/L. The decline in 2001, almost back to the 1992 values, was possibly due to the combined affect of pumping and algal blooms, as suggested by the increases in TOC by end of 2000 (Figure 15 Appendix 2). The projected concentrations of As and Ni removed by pumping support earlier estimates of the effectiveness of biological polishing.

In Figure 5, seasonal changes in As concentration are plotted for each year for each 5 m interval throughout the pit lake. Larger seasonal differences above the thermocline occurred in 1995 and 1996, but as the concentrations decreased, seasonal differences became smaller.

Figure 6a presents Ni concentrations in the same fashion. With one exception, in 1998, the differences above the thermocline were more pronounced than below it, at 35 m. The pattern is consistent with the generation of particles, (both biological in origin and inorganically due to erosion) in the surface water, whereas in the deeper part of the pit lake, particle aggregation and settling are less affected by the seasons. Figure 6b presents actual differences for each year, subtracting the lowest from the highest concentration of

that year. Below 10 m the concentration differences for each year diminish gradually up to 25 m (apart from the noted exception), showing a larger difference at the deepest part of the pit.

In summary, every perspective of data analysis suggests consistency with the two principal contaminant removal processes, TSS generation in the surface water followed by aggregation and settling.

5.1 Natural water cleansing processes for other potential contaminants

It might be argued that reductions of nutrients and other elements in the B- Zone Pit Lake are solely the result of dilution by ground water and atmospheric additions.

Changes in the concentrations of bicarbonate, conductivity, uranium, Ra226, sodium, chloride, aluminum and iron suggest otherwise. If dilution was the sole cause of decreases over time, all of the contaminants, including such environmentally conservative elements as Cl and Na, should decline at a similar rate. And assuming that annual inputs by groundwater and atmospheric precipitation have been reasonably constant, the decline should be consistent

Table 4 summarizes the changes in the elements and compounds being considered, along with the analytical detection limits for these parameters, specifically for the B-Zone Pit Lake analytical runs. For the parameters discussed, the analytical detection limit in this very dilute water is sufficiently low that the measurements are reliable. Concern has been expressed, that concentrations in the pit lake are generally very low and therefore may be unreliable. This is clearly not the case when differences in % removal and increases in some parameters are considered

Table 4 provides the 1993-2001 minimum, maximum and average concentrations and calculations of the percentage decrease/increase for various parameters. The B-Zone

specific analytical detection limits are given in the last column, providing assurance on the validity of the value reported.

A reference point for this examination is a comparison of the 93 % decline of As between 1993 and 2001 (Figure 7 and Table 4) and the comparatively slight decline of 31% of Ni (Figure 8 and Table 4) due to external contributions.

The concentrations of bi-carbonate (Figure 9 and Table 4) increased by 142 % from an average of 13.1 mg/L to 31.8 mg/L between 1993 and 2001. Similarly electrical conductivity increased from a value of about 53.4 µS/cm in 1993 to a value of 87.5 µS/cm in 2001(Figure 10 and Table 4).

The 1993 concentrations of uranium, with an average of 0.026 mg/L dropped 62 % to 0.01 mg/L by 2001 (Figure 11 and Table 4). Ra^{226} total was at 0.143 Bq/L in 1993, falling to 0.018 Bq/L by 2001, a decrease of 87 % (Figure 12 and Table 4). On the other hand, during the same period the dissolved Ra^{226} concentrations decreased 47 % from 0.05 Bq/L to 0.03 Bq/L (Figure 13 and Table 4). For dissolved Ra^{226} the detection limit overlaps the minimum values reported, so those decreases may be less certain. The difference between total Ra^{226} and filtered concentration suggests, that Ra^{226} is associated with the TSS, a key factor in the natural cleaning process.

Changes in Na and Cl, which are relatively conservative, non-reactive elements, are plotted in Figure 14 and 15 respectively. The Na concentration increased by about 34 % between 1993 and 2001 from 1.8 mg/L to 2.4 mg/L, whereas Cl decreased by 59 % In Figure 16 the decrease in Al concentration 99 % , decreasing from 1. 0 mg/L to 0.008 mg/L between 1993 and 2001. Iron concentrations (Figure 17) decreased by about 61 % from 0.75 mg/L to 0.29 mg/L during this period.

The comparisons, summarized in Table 4, should lay to rest the argument that dilution has been a substantial factor in the reduction of contaminants in the lake. The data supports the natural water cleansing processes and the bio-geochemical reactions as key controlling factors of the pit lake chemistry. Furthermore it is of more than passing interest that uranium can be reduced naturally.

6.0 The mass balance of contaminants: sedimentation traps and sediments

This investigation would not be completed if the mass balance of the contaminants in the pit lake and their transport from the water to newly forming sediments was not revisited. Sedimentation data collected in 1997 and 1999, including the elemental composition of the sediment, is reported in Kalin et al. (2000), but are included here for completeness along with additional sedimentation rates and trap material analysis from 2000 and 2001.

For the year 2000, the traps were mechanically fixed with weights and suspended in the lake throughout the year, including the period when the pit lake is ice covered. Previous reports, based on trap results did not include the winter months. Three approaches are presented in relating the results from the sedimentation traps to those found in the sediment.

Section 6.1 considers the sedimentation rate applicable to the entire pit, an estimate most prone to error, as it is hard to accurately assess the surface area within which sedimentation takes place. Section 6.2 uses the sedimentation rate, based on 1 m^2, to estimate a volume for the sediment area of 1 m^2 for the thickness of each layer of sampled sediment (Table 5a). The sediment volume was determined from the wet volume to dry weight ratios for the sediment samples. Section 6.3 considers the mass of contaminants removed from the pit lake in relation to the elemental mass found in the sediment.

6.1. The mass balance for the entire pit lake (1999)

Figure 18 provides sedimentation rates for 1993 and 2001 at depths of 2 m, 12 m, 22 m and 32 m. The rates were considerably higher prior to 1995 but have changed very little since 1997. The time trend in sedimentation rates (Figure 19) suggests that since 1996, the generation of TSS or particulate matter has stabilized at a rate of about 2 g/m^2/day throughout the pit lake, with a further decrease to about 1 g/m^2/day in the last two years. This suggests that in 2000 and 2001 erosion along the shore of the pit lake was minimal. As reported in 1999, single samples of sediment were collected at both the center station

6.72, where the pit lake limnology is monitored to a depth of 45 m, and at station 6.71. Both Ekman grab samples were recovered from a depth between 41 and 45 m.

Estimates of a mass balance of contaminants in sediment and sedimentation trap material were carried out in 1999, by matching the sedimentation rates for 185 days and estimating the horizontal surface area of the pit benches and the area of the bottom of the pit. Details can be found in the 1999 report. (Pages 64-69, Section 3.4). The time period of 0.5 year was chosen, as it can be assumed that during the winter, when the lake turns over and is covered with ice, very little additional sedimentation occurs.

At that time a reasonably good match was obtained for the estimated mass of As in the water column (1.8 t) based on the sedimentation traps and in the bottom sediments; (1.3 t) according to either of the two Ekman grab samples. For Ni the sedimenting material produced 1.7 t of Ni but only 0.7t to 0.9 t was found in the surface layer (0-3cm) of the sediment samples. If however the total Ni and As was considered in all sediment layers (0 to >8 cm) then the amount of Ni and As found in the pit sediment (Ni 2.1 to 2.8 t, As 2.3 to 3.0 t) was higher than in estimates from the sedimentation traps. This discrepancy can be explained by the fact that the sedimentation traps account only for elemental removal since 1993. But the sediments would also include loadings from the first year after flooding (1992), when sedimentation would have been very intense.

6.2 The mass balance per m^2

With the additional samples collected in 1999, we considered the sedimentation rate and the concentrations of contaminants strictly on a one meter square basis. Figures 20a to 20d present concentrations of As, Ni, Fe and P for 1996 to 2001 for the surface sedimentation material (2 m trap) and the material reaching the bottom of the pit (32 m trap). For As, concentrations are consistently higher at the bottom, and with the exception of the year 1998 at 32 m, are generally in the same range.. At the surface, iron concentrations are about 15 times higher than As concentration, which is reduced to about 10 times at the bottom. Over the years, there is more iron in the sedimentation material

likely reflecting the increasing pH, which promotes precipitation of iron-hydroxide (Figure 20c).

For Ni, the surface sedimentation trap material is consistently higher in concentration than at the bottom. This provides further evidence that Ni removal is influenced by negatively-charged organic cell walls produced by algae and the decay of the biomass as it moves toward the bottom of the pit (Figure 20b).

In the years 1998 and 2001 higher phosphate concentrations was reported in the material of the sedimentation traps on the surface (Figure 20d). These higher values may be due to biological activity, such as an algal bloom, as it is only noticeable in the surface traps.

Evidence that contaminant removal is related to TSS or particulate material is found in Plate 1 where the sedimentation traps for the year 2000 are depicted. This photo indicates clearly a heavy TSS loading on the surface sedimentation trap. The coverings appear to be formed of a slimy film combining organic with inorganic particulate matter. This coating was not present in earlier years. In summary, an active biological component is feasible, but can not be substantiated solely based on analysis of sedimentation trap contents. Analysis of the solid material collected in the sedimentation traps indicates that both Ni and As continue to be transported to the sediments.

In order to match concentrations in the sediments with those found in the sedimenting material, samples were collected in 1999 with Ekman grabs from two stations (6.71 and 6.72). The depth of the samples retrieved was between 45 and 41 m, measured by the extension of the sampling rope. It should be noted that the length of the rope is not the true depth, as it is always at an angle with respect to the boat as it is never truly vertical. The boat was anchored to floats marking the sampling stations. Several Ekman grab samples were extracted and visually distinct layers are described and separated for analysis.
In Plate 2, the surface layer is shown from the grab sample #5. Plate 3 shows the iron hydroxide precipitate after removal of the 0-1 cm layer Plate 4 depicts the texture of the 3rd and 4th layer from the same sample. These lower layers reflect the early years of heavy TSS sedimentation in the pit. Plate 5 shows grab sample #1 from the same station (6.72)

which is quite similar to the previous one collected at this location.

The layers from each grab sample were processed and mixed for each station according to their similarity in texture. This provided representative concentrations of elements for the sampling location, by the depth of the layer. The sediment sample layers were combined for Grab # 1 and 3 as they were similar, and Grab # 2 was analyzed separately for Station 6.71 (Table 5a). In Table 5b the Station 6.72 results are presented for the layers of Grab # 1, which had very similar layers as Grab #2, which was not analyzed for this station. For Grabs # 3, 4, 5 and 6, similar layers were mixed prior to submission for chemical analysis to SRC. The elemental composition of the sediment and its layers is therefore based on the analysis of a combined sample representing the layers of sediment obtained from Grabs #3, 4, 5 and 6 (mixed) and one analysis of each layer separately (unmixed). The concentrations found in the sedimentation trap material and the concentrations in the sediments are therefore assessed based on a total of 9 grab samples for two stations in the pit lake.

From each grab sample layer, a sub-sample wet volume (60 ml) was withdrawn. Wet weight and dry weight were determined to arrive at moisture content. Generally the upper layers of each grab sample had a high moisture content ranging from 77 % to 83 %, whereas the clay layers generally found at 2 -6 cm had lower moisture contents of 34 % - 38 %, as would be expected (Table 5a and Table 5b). The concentrations in the various layers are given in the next row of Table 5a for stations 6.71 and in Table 5b for stations 6.72. Both tables include concentrations for the two samples collected in 1997 for the equivalent layers.

The surface layers have higher arsenic concentrations compared to the lower clay layer for As. The distribution of Ni concentration in the layers at Station 6.71 suggests that the highest concentrations are in the clay layers. This was not the case at Station 6.72 where samples collected in 1997 indicated higher concentrations in the surface layers and lower concentrations in the deeper layers. One would have expected the highest concentrations to have been found in the deeper layers, laid down in the early years of the pit lake. However the layers were separated for analysis based on visual differences, which do not necessarily reflect the time since deposition. In addition, the mechanics of the separation

might have introduced some mixing of the layers which could have affected the reported concentrations in the layers.

Comparing sedimentation rates, which are calculated per meter square, to values derived for one square meter of sediment, the depth of the layer (0-1 , 1-2 cm etc) sampled is converted to a volume of 1 m^3 using the layers accordingly for example a thin layer . with 0.005 m^3 /m^{-2} to a thick layer of 0.04 m^3/ m^{-2} . The conversion to volume is based on the wet volume to dry weight ratio determined for each sample layer. To estimate the mass of the elements on a per square meter basis**,** a unit of g dry weight m^{-2} in each sediment layer is converted from the concentration determined from the dry sample. The conversions are also made, for elements U, Al, Fe and P, where the transport mechanism was studied in detail. Those elements provide additional confidence in the mass balance, derived from the sedimentation trap material and the mass equivalent cumulated in the sediment. The data used to arrive at the mass g per meter squared are presented in Table 5a and in Table 5b. In addition sediment samples can be compared for station 6.72 and 6.71, in the same area of the pit bottom.

Sediment concentrations per m^{-2} for each layer were summed to yield total load for comparison with the sedimentation trap material loading (Table 6). For 1992, the same sedimentation rate as 1993 was used. The 1992 trap was suspended for a very short period; hence the readings that year may be unreliable. Between 1992 and 1999, a total of 33.7 kg/m^2 of material had accumulated on the lake bottom, assuming that sedimentation occurs 365 days a year.

Table 6 also provides concentrations of contaminants in the sedimenting material collected in the surface and 32 m sedimentation traps in 2000 and 2001 . Arsenic concentrations are of the same order of magnitude in the deeper traps as in previous years. For Ni, surface concentrations are higher reflecting the values discussed with Figure 20b.

Arsenic sedimenting in the pit lake in 2000 and 20001 was the lowest it has ever been. But nickel was of the same magnitude suggesting that the process of contaminant removal has remained the same. The high Ni concentrations at the surface sedimentation trap may

either be due to the inorganic material and/or algal bloom. This latter suggestion is supported by higher sedimentation trap phosphate in 2001 and elevated TOC in the water column in 2000. This would suggest that despite the reduced nutrient status, some level of biological activity is still removing contaminants.

Figure 21 summarizes results based on Table 5 and 6, comparing the mass of the elements which has cumulatively settled since 1992 in the sedimenting material, as quantified by the sedimentation traps, versus concentrations in the sediment. Each sediment grab sample is plotted for comparison with sedimentation trap results for As, Ni, PO_4, Fe and Al. The agreement between the two materials is very reasonable for Fe and PO_4 in two of the four grab samples. The agreement for As is reasonable in one out of the four grab samples. For Al generally the concentrations in the sediments are higher than the concentrations in the sediment trap material, which was to be expected as the clay particles are rich in Al.

6.3 Mass balance - water

The changes in chemistry in the B-Zone Pit Lake are the product not of dilution by significant external sources, but of ongoing bio-geochemical reactions. The changes in chemistry, along with the accounting of the contaminants suggest that the lake is a well-defined, closed system.

The most active zone of contaminant removal is the surface volume of the pit lake from 0 - 5 m. The reason for this is evident in Plate 1 which illustrates the intense covering of particulate matter recovered in 1999 by the 2m, near-surface sedimentation traps. In the early years, the appearance of the surface traps was quite different (Plate 1 page 47, 1997 report), in that the organic component was dominated by algal growth. In later years this appears to have been replaced with inorganic material.

The visual documentation provided by the sedimentation traps supports the contention that the active layer is the surface layer of the pit lake (Plate 1) . From these visual observations

of the sedimentation traps, in the beginning of the pit lake, biology and TSS were clearly the driving engines of contaminant removal. This is no doubt still true, although the contribution of the two components may have shifted.

Assessing the mass of elements in the pit lake for the first 0-5 m will give some overall perspective and mass balance (Table 7a to 7d). Each year, before the start of pumping, about 60 kg of Ni was removed from the surface layer. Pat Landine of Cameco (Appendix 5) estimated an annual Ni input of about 100 kg from the "Blue Road". As noted, this agrees, in general, with the quantities required for replenishing of the surface water concentrations. Since the start of pumping, reductions in Ni during the summer months have been smaller (Table 7a).

The same pattern of removal from the surface layer is noted for As, although it has been less pronounced since the start of pumping (Table 7b). No clear picture is evident in the irregular removal of Fe and Al from the surface layer water (Table 7c and 7d).. In summary, pumping appears to have reduced concentrations only slightly.

7.0 Conclusions

Limnological conditions documented for the B-zone Pit Lake between 1992 and 2001 support the concept that the natural cleansing processes in the lake have effectively reduced contaminants. The processes have now been documented in eight reports, two conference proceedings and one peer reviewed journal article. In recent years, nutrient limitations have reduced, but not eliminated the efficiency of the processes a condition that could be corrected if regulators approved the addition of fertilizer to the lake.

This study began with the assumption that the B-Zone pit lake is a closed system, with no external input of contaminants. This could be documented for all contaminants, but not for Ni. The mass balance of Ni in the water and settling in particulate matter to the sediment revealed an excess in the bottom sediment. An external source of Ni was sought and identified as evaporites along a perimeter road. Ni load estimates to the pit lake from the road agreed, within an order of magnitude, with the seasonal replenishment of Ni washed into the pit lake during rain events. The problem was corrected in October 2001. It is concluded that the B-Zone pit decommissioning work has accounted for all contaminant sources and demonstrated the ongoing natural contaminant removal processes at work in the pit. When water quality criteria have been established, the pit lake should be considered ready for integration with Collins Bay.

Since 1999, water has been pumped out of the pit lake, actively removing contaminants and making it possible to quantify and verify by tests that no other contaminants enter the lake. Dilution is not a significant factor. The agreement of the predicted and measured concentrations verifies virtually all previous assumptions made about the closed pit lake system. From a scientific or technical perspective, the lake is a perfectly closed system, perhaps unique in the quality of its extensive water quality database.

These investigations of the B-Zone Pit Lake has been a delight for the enthusiastic ecological engineer who conducted them; they have advanced the field of Ecological

Engineering, and yielded valuable information that will aid in the manipulation and management and recovery of similarly man-made lakes. Cameco Corporation deserves great credit for sponsoring and supporting this research.

8.0 References cited

Buffle, J., and H.P. VanLeeuen, 1992: Environmental Particles Vol. I, Lewis Publishers.

Davis, A., and D. Ashenberg, 1989: The aqueous geochemistry of the Berkley Pit, Butte Montana, U.S.A. Applied Geochemistry 4: 23-36.

Doyle, G.A., Pillard, D.A., Runnells, D.D. and J. Young, 1995: Post mining pit lakes, prediction lake chemistry and ecological risks. Tailings and Mine Waste: 469-478. Proceedings of the third international conference on tailings and mine waste, 1996 Fort Collins, Colorado, U.S.A. A. A. Balkema Publishers.

Geller, W., H., Klapper and W. Salomons, 1998: Acidic Mining Lakes, Springer-Verlag, New York.

Levy, D.B., K.H. Custis, W.H. Casey, and P. A. Rock, 1996: Geochemistry and physical limnology of an acidic pit lake. Tailings and Mine Waste: 479-489.

Lowson, E.A. 1997: Chemical, physical and biological characteristics of particulates formed in mine drainage systems. MSc thesis, University of Toronto.

Sawchyn, W. W. 1973: Wollaston Lake limnological investigations.
Saskatchewan Research Council

Stumm and Morgan 1995: Aquatic Chemistry. Wiley and Son.

Kalin, Cao and Smith, 2000: Sedimentation in a pit lake in relation to Water Quality Changes, Proceedings of the International Symposium on the process metallurgy of uranium. Uranium 2000, Saskatoon Saskatchewan, Sept. 9-15 pp 613-629.

Kalin, Cao, Smith and Olaveson, 2001: Development of the phytoplankton community in a Pit lake in relation to water quality changes. Water Research, Vol. 35, # 13 pp 3215 -3225.

Note: Reports and other publication related to B-zone pit are listed in Appendix 1

Appendix: Update 2001 – 2004

Water quality data generated for the B-Zone Pit Lake between 1992 and 2001 revealed seasonal decreases in the concentration of both arsenic and nickel. These were attributed to the primary productivity in the photic zone of the pit lake.

Reductions in nickel concentrations above the thermocline were observed during the summer months, however by the spring of the following year, after the turn over of the lake, Ni concentrations increased to levels similar to that of the previous spring. It was suggested that during the late summer months, decaying biomass at the thermocline was releasing Ni back into the water column. However a mass balance of the contaminants in TSS collected in sedimentation traps, agreed with the cumulative mass determined for the sediment layer of 0 -7 cm for Ni, as well as As, Fe, As, P and Al. This suggested that the renewed Ni in the surface waters of the lake came from an external source. This was subsequently identified as mineralized material in a nearby perimeter road. By the end of 2001 this mineralized material had been removed.

In the long run, the singularity in the Ni data as compared all other elements, strengthened the conclusions being derived from all observations of the pit lake limnology. With the elimination of the pit road, the seasonal trends in Ni concentrations fell into line with the trends observed for all other contaminants. The rate of contaminant removal is now expected to decrease as nutrient levels in the pit are being exhausted.

Since the road was cleaned up, the frequency of sampling water quality has been maintained but the levels that samples are drawn from have been reduced to three; from the surface, (depth of 0 m) middle (20 m) and bottom (40 m) of the lake. This makes it difficult to precisely interpret seasonal variations. Nonetheless the 2001-2004 data should reveal an annual pattern in Ni concentration and dispersal; the winter turnover of the lake will equalize top and bottom concentrations; contaminant levels will remain constant in June to July assuming the clean-up of the perimeter road was effective; the growth of phytoplankton to the extent permitted by available nutrients, should bring about a decrease in August – September; and by October Ni concentrations in surface waters should be at their lowest for the year.

With the exception of a single reading in June, Ni concentrations since 2002 have been in the range 0.13 mg/l to 0.19 mg /l.; by 2003 no differences in concentrations of Ni between top and bottom were evident. In Figure 1a to 1d, data are plotted for the same sampling stations for 1999 to 2004, to assess the overall trend in concentration in the pit lake.

A continued reduction of the contaminants would also support limnological interpretations which have identified the components of the contaminant removal process. Since concentrations have decreased or remained within the range of 0.13 mg/l to 0.18 mg/l for 2003 and 2004, it can be concluded that the perimeter road cleanup has been successful. However, the pit has likely run out of nutrients to support significant phytoplankton production.

Concentrations of arsenic have generally decreased since 2002, with the exception of a single reading (August 2003, of 0.02 mg/l at the surface), to values below 0.01 mg/l (Figures 2a to 2d). The raw data for both nickel and arsenic are given in this appendix covering the period of 1995 to 2004.

Appendix 1

List of Reports

LIST OF REPORTS

1. Boojum Research Limited, January 1995. **The Decommissioning of the B-Zone Flooded Pit with Ecological Engineering.** Submitted to CAMECO Corporation, 128 pp.
2. Kalin, M., and M. Olaveson, 1996. **Controlling factors in the production of extracellular polysaccharides in phytoplankton,** 188 pp. CANMET contract # 23440-5-1136/01 SQ.
3. Kalin, M. 1997. **Nickel and arsenic adsorption onto mucilage producing algal colonies,** 48 pp. CANMET Biotechnology: CANMET contract # 23440-6-1011/001/ SQ.
4. Kalin, M., W.N. Wheeler and M.P. Smith, 1997. **The role of Picoplankton as primary producers in mining waste water effluents,** 432 pp. CANMET contract # 23440-5-1302/001/ SQ.
5. Lowson, E.A., 1997. **Chemical, physical and biological characteristics of particulates formed in mine drainage systems**. University of Toronto, Msc. Thesis under supervision of F.G. Ferris.
6. **B-Zone Pit: Limnology 1993-1996 and the fate of arsenic and nickel**. April 1997. pp 265. Submitted to CAMECO Corporation, 265 pp.
7. **B-Zone Pit: The fate of arsenic and nickel. The proof is in the sediment**. Final report 1998, pp 123. February 1998.
8. **Phytoplankton in mine waste water community structure, control factors and biological monitoring**, 239 pp. Biotechnology for mining: CANMET Contract # 23440-8-1016/001/SQ. June 1999.
9. Kalin, M., Y. Cao, M. Smith and M. Olaveson, 2001. **Development of the phytoplankton community in a Pit-Lake in Relation to Water Quality Changes**, Water Research (35 ;13) pp. 3215-3225.
10. Nalewajdo, C. and Olaveson, M. (1998). **Ecophysiological considerations in**

microalgal toxicity tests. In: Wells, P. G., Lee, K. and Blaise, C. (eds.) Microscale Aquatic Toxicology: Advances, Techniques and Practice. (Chapter 19). CRC Lewis Publishers. Bocal Raton, Florida. 20 pp.

11. Kalin, M., 2000. **The Role of Applied Biotechnology in Decommissioning Mining Operations"**, Proceedings of the Beijing International Symposium on Land Reclamation, "Mine Land Reclamation and Ecological Restoration fro the 21 Century', Beijing, China, May 16-18, pp. 544-554.
12. Kalin, M., M.P. Smith and Y.Cao, 2000. **Sedimentation in a Pit Lake in Relation to Water Quality Changes**, Proceedings of the International Symposium on the Process Metallurgy of Uranium, Uranium 2000, Saskatoon, Saskatchewan, September 9-15, pp. 613-629.

List of Publications Forthcoming

1. Olaveson, M.M., Engels, M., Kalin, M. and Nalewajko, C. **Nutrient limitation as a trigger for mucilage production in *Dictyosphaerium pulchellum***. To be submitted to Journal of Phycology.
2. Olaveson, M.M., Engels, M., Kalin, M. and Nalewajko, C. **Growth and photosynthetic response of *Dictyosphaerium pulchellum* to elevated nickel concentrations**. To be submitted to Journal of Phycology.
3. Kalin, M. et al. **Estimates of primary productivity for three flooded open-pit uranium mines.** To be submitted to Journal of Water Research**.**

Appendix 2

B-ZONE PIT LIMNOLOGY
1992-2001

LIST OF TABLES

LIST OF FIGURES

Table 1a: Nutrient concentration in the flooded pit, 1995.

1995		Depth	Nutrients, mg/L			
			PO_4	NO_3	NH_4	N,TKN
		0	0.46	0.44	0.01	
April 12		5	0.43	0.44	0.03	
		10	0.40	0.40	0.01	
		15	0.40	0.35	0.03	
		20	0.40	0.44	0.03	
		25	0.40	0.57	0.03	
No Thermocline		30	0.37	0.44	0.01	
		35	0.37	0.53	0.03	
		40	0.49	0.70	0.01	
		45			0.04	
	Average		**0.41**	**0.48**	**0.02**	
	Above	0	0.40	0.13	0.05	0.24
June 14	Below	5		0.53		
	Thermo-	10	1.38	0.35	0.05	0.14
	cline	15	0.28	0.40	0.08	0.31
		20	0.21	0.35	0.03	0.16
		25	0.28	0.40	0.12	0.24
Thermocline 3 m		30	0.40	0.40	0.10	0.63
		35	0.46	0.35	0.03	0.8
		40	0.49	0.44	0.07	0.27
	Average	**Above**	**0.40**	**0.13**	**0.05**	**0.24**
		Below	**0.50**	**0.40**	**0.07**	**0.36**
		0	0.37	0.04	0.10	
Aug 17		5	0.46	0.04	0.05	
	Above	10	0.77	0.35	0.05	
	Below	15	0.37	0.31	0.04	
	Thermo-	20	0.40	0.35	0.05	
	cline	25	0.52	0.44	0.18	
		30	0.52	0.48	0.09	
Thermocline 10 m		35	0.61	0.40	0.13	
		40	0.64	0.62	0.22	
		45	0.77	0.40	0.04	
	Average	**Above**	**0.53**	**0.14**	**0.07**	
		Below	**0.57**	**0.42**	**0.10**	
		0	0.37	0.13	0.05	
Oct 14		5	0.43	0.09	0.03	
		10	0.31	0.09	0.05	
		15	0.28	0.18	0.03	
	Above	20	0.43	0.09	0.03	
	Below	25	0.18	0.31	0.08	
	Thermo-	30	0.31	0.48	0.03	
	cline	35	0.43	0.48	0.03	
Thermocline 20 m		40	0.49	0.44	0.03	
	Average	**Above**	**0.36**	**0.11**	**0.04**	
		Below	**0.37**	**0.36**	**0.04**	

Table 1b: Nutrient concentration in the flooded pit, 1996.

1996		Depth	Nutrients, mg/L			
			PO_4	NO_3	NH_4	N,TKN
May 9		0	0.40	0.66	0.03	
		5	0.40	0.75	0.01	
		10	0.37	0.75	0.03	
		15	0.40	0.48	0.03	
		20	0.40	0.48	0.03	
		25	0.40	0.53	0.03	
No Thermocline		30	0.31	0.57	0.04	
		35	0.37	0.35	0.04	
		40	0.40	0.18	0.04	
	Average		**0.38**	**0.53**	**0.03**	
Aug 26		0	0.24	0.04	0.05	
	Above	5	0.21	0.04	0.03	
	Below	10	0.21	0.04	0.02	
	Thermo-	15	0.21	0.04	0.01	
	cline	20	0.24	0.04	0.05	
		25	0.21	0.04	0.10	
Thermocline 9 m		30	0.21	0.04	0.04	
		35	0.31	0.09	0.03	
		40	0.37	0.13	0.04	
	Average	**Above**	**0.22**	**0.04**	**0.03**	
		Below	**0.25**	**0.06**	**0.04**	
Oct 28		0	0.34	0.13	0.01	
		5	0.31	0.18	0.04	
		10	0.31	0.13	0.01	
		15	0.31	0.09	0.05	
		20	0.31	0.22	0.03	
		25	0.31	0.13	0.01	
No Thermocline		30	0.31	0.18	0.01	
		35	0.37	0.13	0.01	
		40	0.64	0.04	0.05	
	Average		**0.35**	**0.14**	**0.03**	

Table 1c: Nutrient concentration in the flooded pit, 1997.

1997		Depth	Nutrients, mg/L			
			PO_4	NO_3	NH_4	N,TKN
		0	0.30	0.04	0.10	
29-Jun	Above	5	0.30	0.04	0.10	
	Below	10	0.09	0.04	0.10	
	Thermo-	15	0.33	0.04	0.12	
	cline	20	0.42	0.04	0.10	
		25	0.48	0.04	0.09	
Thermocline 6 m		30	0.33	0.04	0.08	
		35	0.39	0.04	0.09	
		40	0.42	0.04	0.10	
	Average	**Above**	**0.30**	**0.04**	**0.10**	
		Below	**0.35**	**0.04**	**0.10**	
		0		0.04	0.05	
12-Aug	Above	5		0.04	0.05	
	Below	10		0.04	0.04	
	Thermo-	15		0.04	0.04	
	cline	20		0.04	0.03	
		25		0.04	0.04	
Thermocline 8 m		30		0.04	0.03	
		35		0.04	0.03	
		40		0.18	0.05	
	Average	**Above**		**0.04**	**0.05**	
		Below		**0.06**	**0.04**	
		0	0.27	0.22	0.08	
06-Oct		5	0.24	0.18	0.08	
	Above	10	0.24	0.18	0.10	
	Thermo-	15	0.21	0.18	0.09	
	cline	20	0.21	0.22	0.21	
	Below	25	0.18	0.31	0.13	
Thermocline 23 m		30	0.18	0.26	0.16	
		35	0.18	0.31	0.16	
		40	0.24	0.35	0.18	
	Average	**Above**	**0.23**	**0.19**	**0.11**	
		Below	**0.20**	**0.31**	**0.16**	

Table 1d: Nutrient concentration in the flooded pit, 1998.

1998		Depth	Nutrients, mg/L			
			PO_4	NO_3	NH_4	N,TKN
		0	0.86	0.26	0.04	
18-Apr		5	0.34	0.26	0.04	
		10	0.34	0.18	0.03	
		15	0.28	0.22	0.03	
		20	0.24	0.22	0.04	
		25	0.28	0.26	0.04	
No Thermocline		30	0.21	0.26	0.05	
		35	0.24	0.26	0.05	
		40	0.21	0.35	0.05	
	Average		**0.33**	**0.25**	**0.04**	
		0	0.61	0.04	0.07	
01-Jun		5	0.31	0.04	0.08	
		10	0.24	0.04	0.08	
		15	0.28	0.13	0.07	
		20	0.12	0.09	0.04	
		25	0.18	0.18	0.05	
No Thermocline		30	0.18	0.09	0.05	
		35	0.21	0.13	0.04	
		40	0.55	0.13	0.07	
	Average		**0.30**	**0.10**	**0.06**	
		0	0.18	0.04	0.05	
02-Sep	Above	5	0.43	0.04	0.04	
	Below	10	0.24	0.04	0.04	
	Thermo-	15	0.18	0.04	0.04	
	cline	20	0.31	0.04	0.01	
		25	0.18	0.04	0.03	
Thermocline 10 m		30	0.15	0.04	0.05	
		35	0.18	0.04	0.07	
		40	0.15	0.16	0.05	
	Average	**Above**	**0.31**	**0.04**	**0.05**	
		Below	**0.20**	**0.06**	**0.04**	

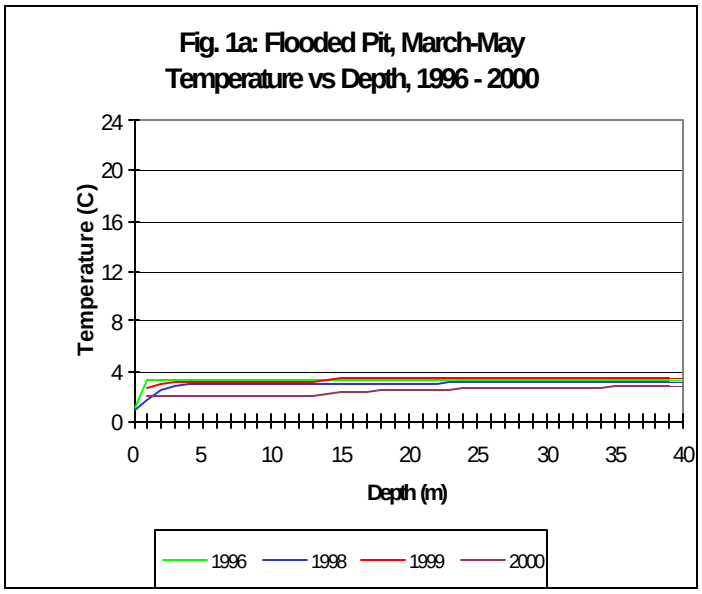


Fig. 1a: Flooded Pit, March-May
Temperature vs Depth, 1996 - 2000
Temperature (C)
Depth (m)
1996
1998
1999
2000

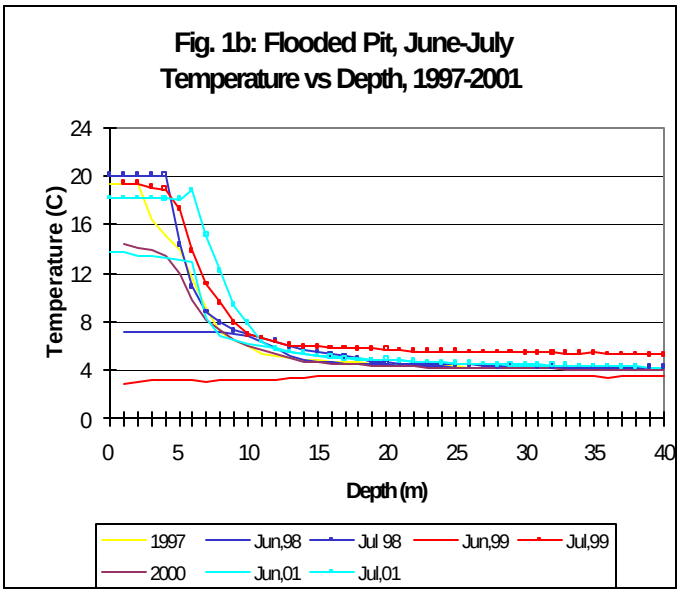


Fig. 1b: Flooded Pit, June-July
Temperature vs Depth, 1997-2001
Temperature (C)
Depth (m)
1997
Jun,98
Jul 98
Jun,99
Jul,99
2000
Jun,01
Jul,01

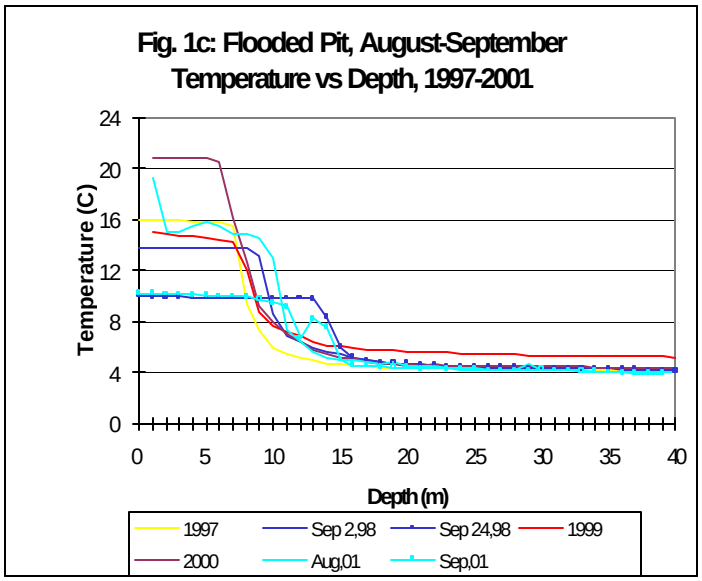


Fig. 1c: Flooded Pit, August-September
Temperature vs Depth, 1997-2001
Temperature (C)
Depth (m)
1997
Sep 2,98
Sep 24,98
1999
2000
Aug,01
Sep,01

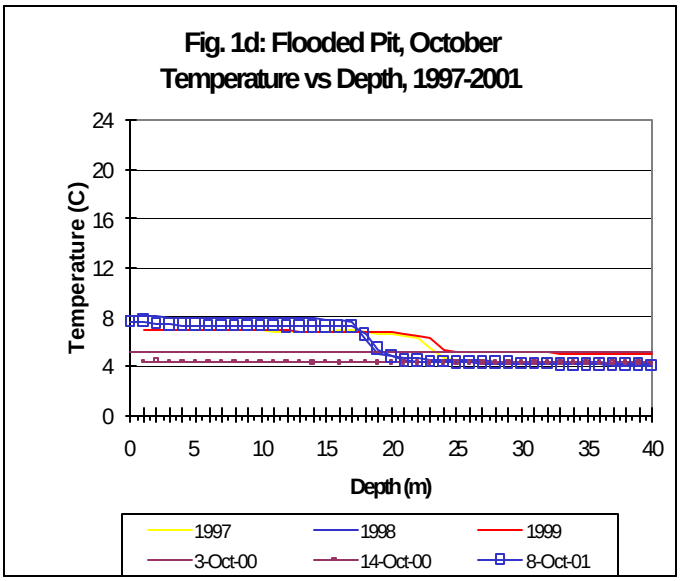


Fig. 1d: Flooded Pit, October
Temperature vs Depth, 1997-2001
Temperature (C)
Depth (m)
1997
1998
1999
3-Oct-00
14-Oct-00
8-Oct-01

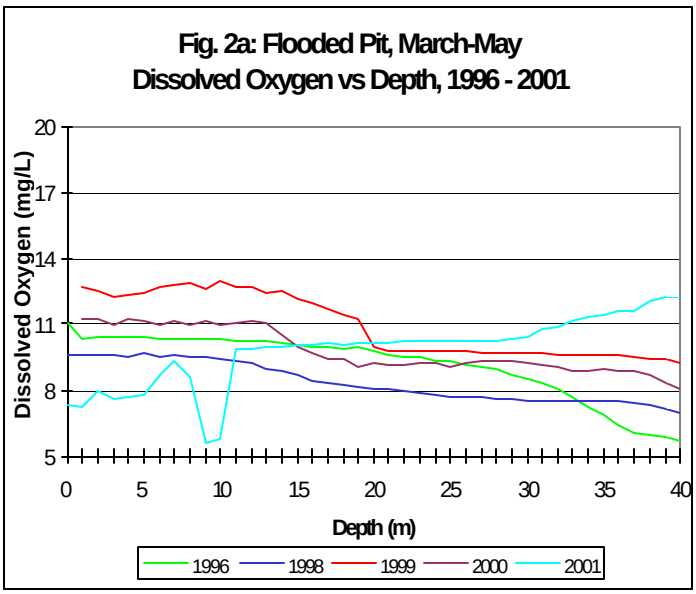


Fig. 2a: Flooded Pit, March-May
Dissolved Oxygen vs Depth, 1996 - 2001
Dissolved Oxygen (mg/L)
20
17
14
11
8
5
0
5
10
15
20
25
30
35
40
Depth (m)
1996
1998
1999
2000
2001

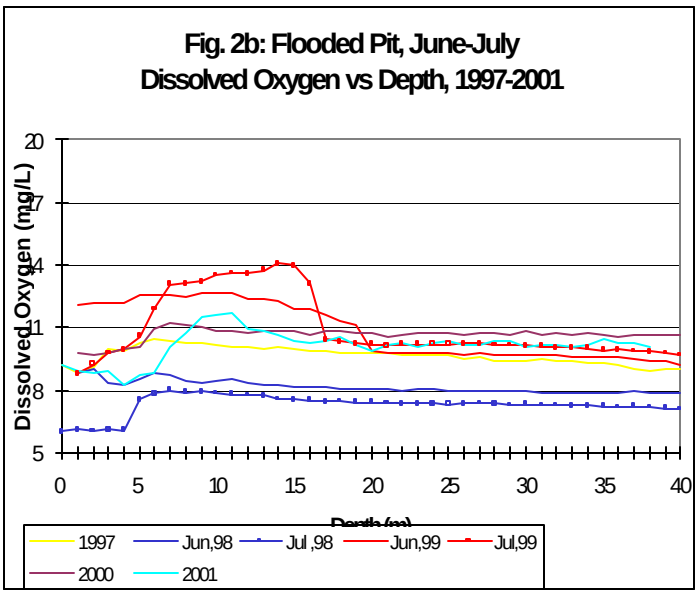


Fig. 2b: Flooded Pit, June-July
Dissolved Oxygen vs Depth, 1997-2001
Dissolved Oxygen (mg/L)
20
17
14
11
8
5
0
5
10
15
20
25
30
35
40
1997
Jun,98
Jul ,98
Jun,99
Jul,99
2000
2001

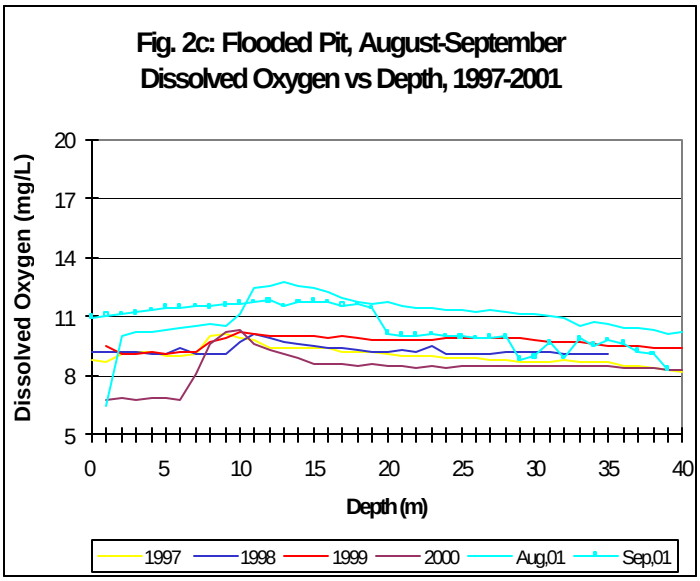


Fig. 2c: Flooded Pit, August-September
Dissolved Oxygen vs Depth, 1997-2001
Dissolved Oxygen (mg/L)
20
17
14
11
8
5
0
5
10
15
20
25
30
35
40
Depth (m)
1997
1998
1999
2000
Aug,01
Sep,01

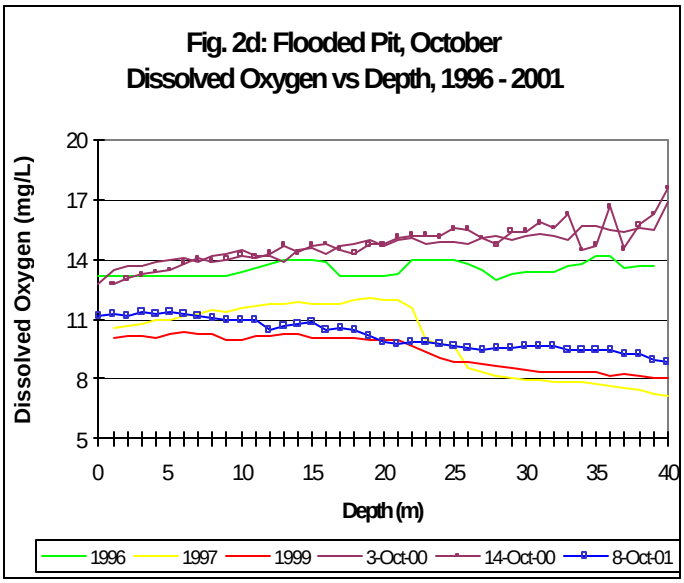


Fig. 2d: Flooded Pit, October
Dissolved Oxygen vs Depth, 1996 - 2001
Dissolved Oxygen (mg/L)
20
17
14
11
8
5
0
5
10
15
20
25
30
35
40
Depth (m)
1996
1997
1999
3-Oct-00
14-Oct-00
8-Oct-01

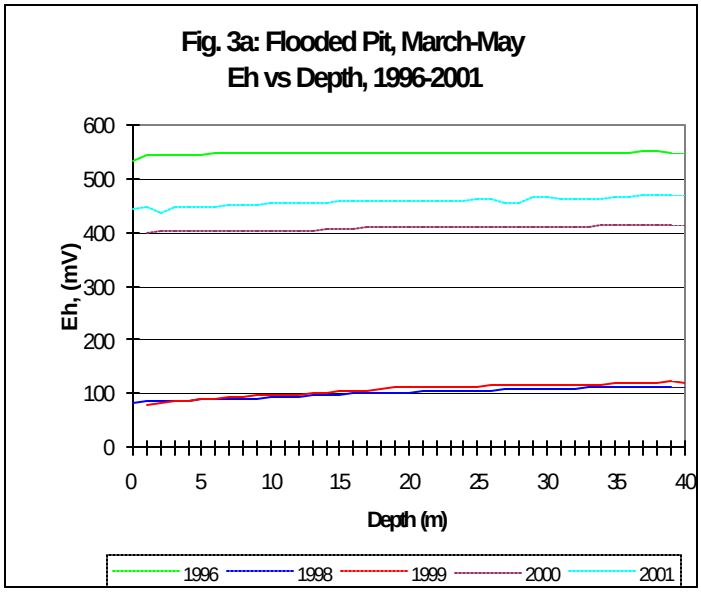


Fig. 3a: Flooded Pit, March-May
Eh vs Depth, 1996-2001
Eh, (mV)
Depth (m)
1996
1998
1999
2000
2001

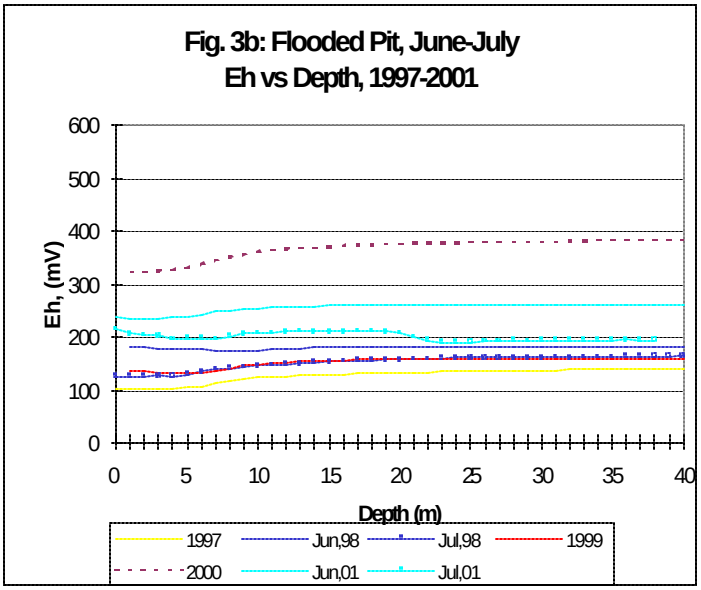


Fig. 3b: Flooded Pit, June-July
Eh vs Depth, 1997-2001
Eh, (mV)
Depth (m)
1997
Jun,98
Jul,98
1999
2000
Jun,01
Jul,01

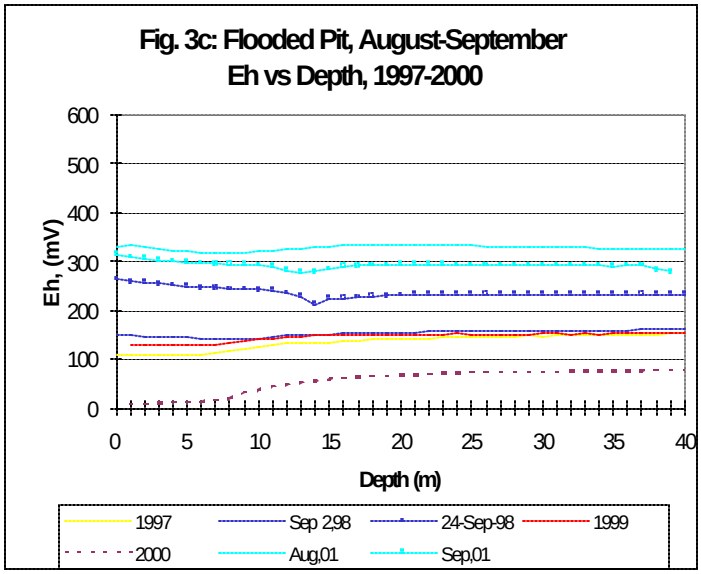


Fig. 3c: Flooded Pit, August-September
Eh vs Depth, 1997-2000
Eh, (mV)
Depth (m)
1997
Sep 2,98
24-Sep-98
1999
2000
Aug,01
Sep,01

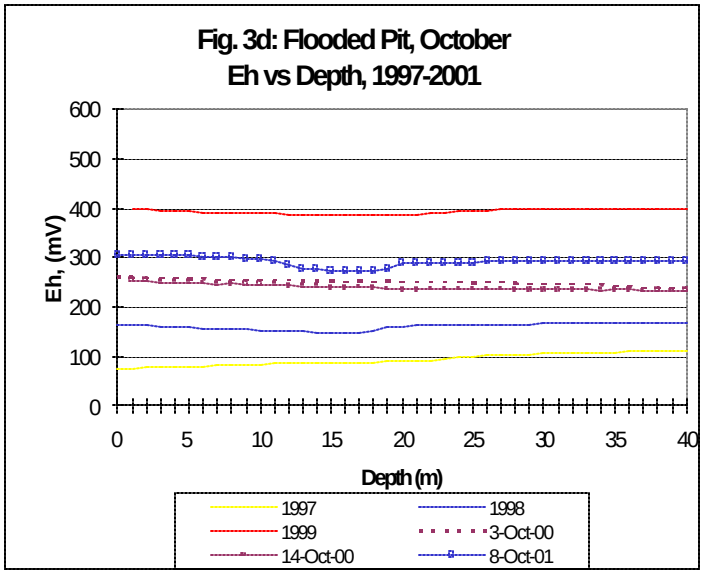


Fig. 3d: Flooded Pit, October
Eh vs Depth, 1997-2001
Eh, (mV)
Depth (m)
1997
1998
1999
3-Oct-00
14-Oct-00
8-Oct-01

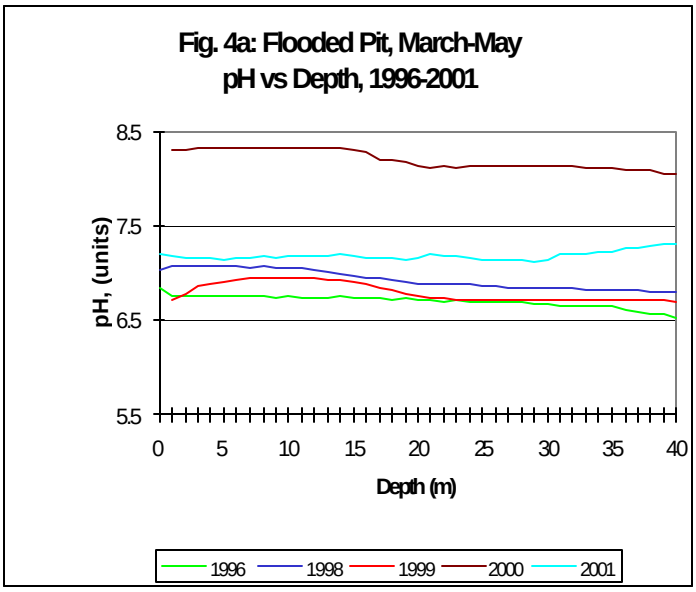


Fig. 4a: Flooded Pit, March-May
pH vs Depth, 1996-2001
pH, (units)
8.5
7.5
6.5
5.5
0 5 10 15 20 25 30 35 40
Depth (m)
1996 1998 1999 2000 2001

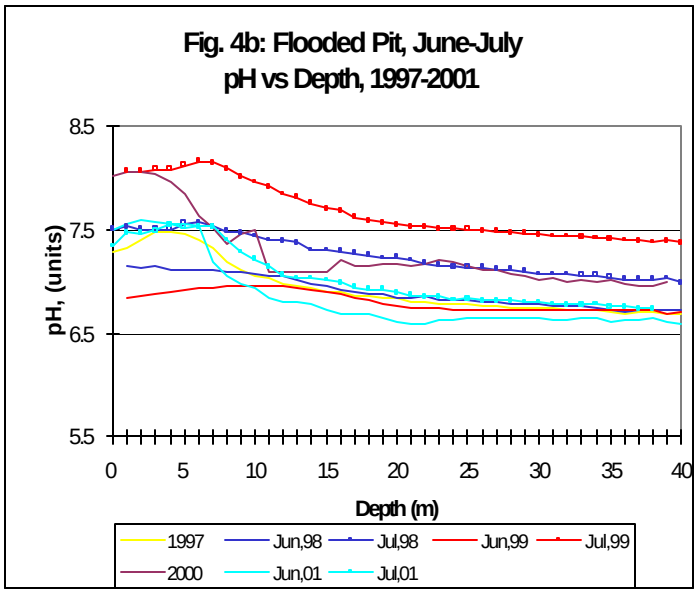


Fig. 4b: Flooded Pit, June-July
pH vs Depth, 1997-2001
pH, (units)
8.5
7.5
6.5
5.5
0 5 10 15 20 25 30 35 40
Depth (m)
1997 Jun,98 Jul,98 Jun,99 Jul,99
2000 Jun,01 Jul,01

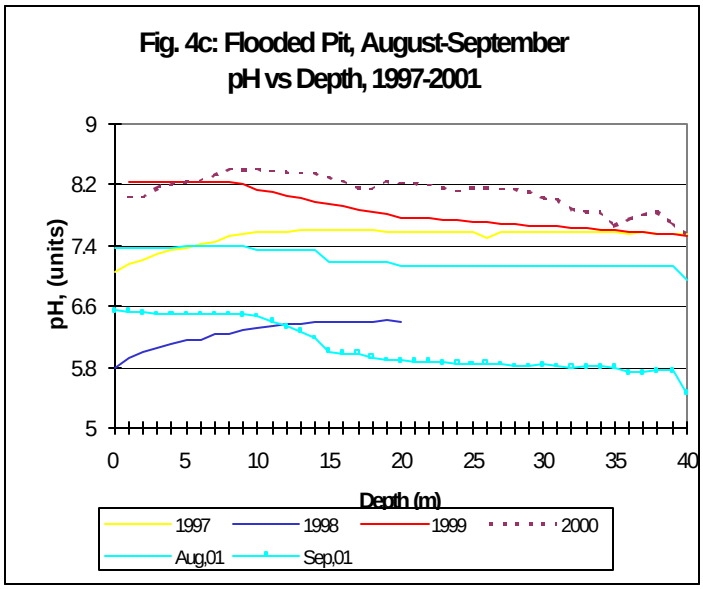


Fig. 4c: Flooded Pit, August-September
pH vs Depth, 1997-2001
pH, (units)
9
8.2
7.4
6.6
5.8
5
0 5 10 15 20 25 30 35 40
Depth (m)
1997 1998 1999 2000
Aug,01 Sep,01

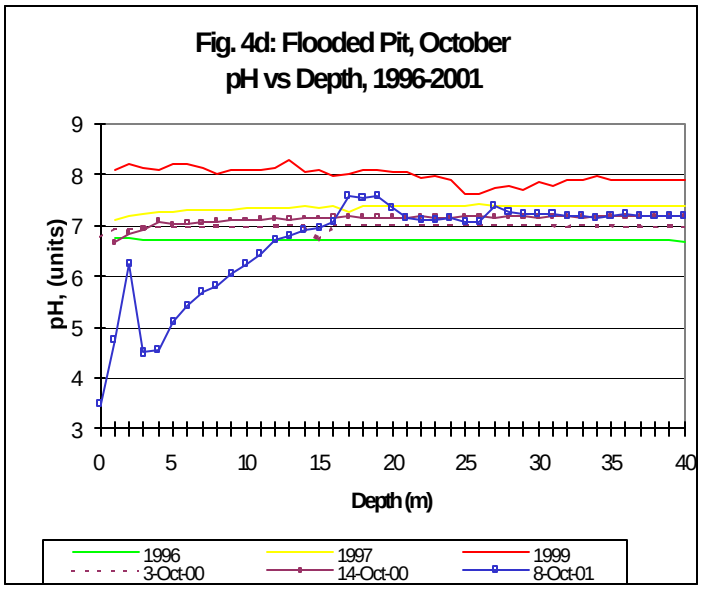


Fig. 4d: Flooded Pit, October
pH vs Depth, 1996-2001
pH, (units)
9
8
7
6
5
4
3
0 5 10 15 20 25 30 35 40
Depth (m)
1996 1997 1999
3-Oct-00 14-Oct-00 8-Oct-01

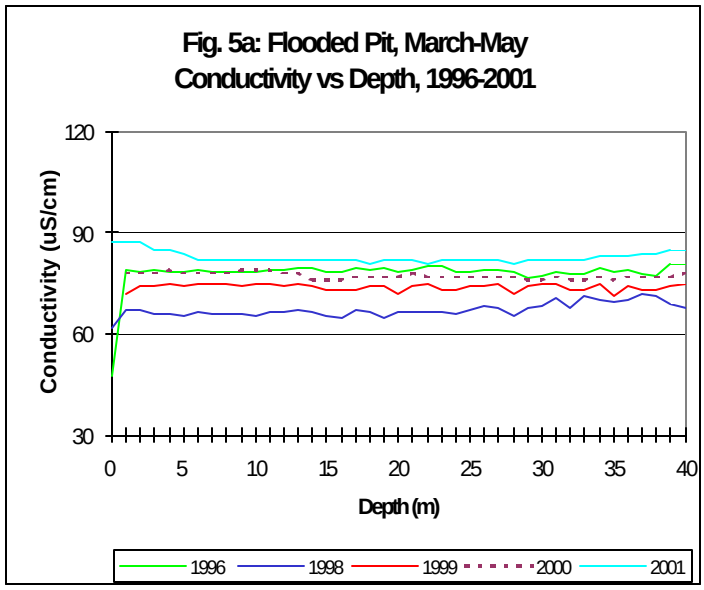


Fig. 5a: Flooded Pit, March-May
Conductivity vs Depth, 1996-2001
Conductivity (uS/cm)
120
90
60
30
0
5
10
15
20
25
30
35
40
Depth (m)
1996
1998
1999
2000
2001

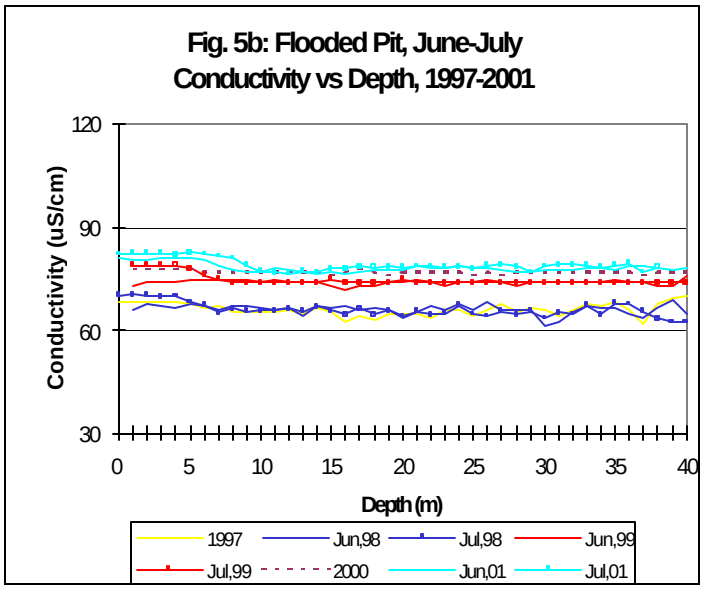


Fig. 5b: Flooded Pit, June-July
Conductivity vs Depth, 1997-2001
Conductivity (uS/cm)
120
90
60
30
0
5
10
15
20
25
30
35
40
Depth (m)
1997
Jun,98
Jul,98
Jun,99
Jul,99
2000
Jun,01
Jul,01

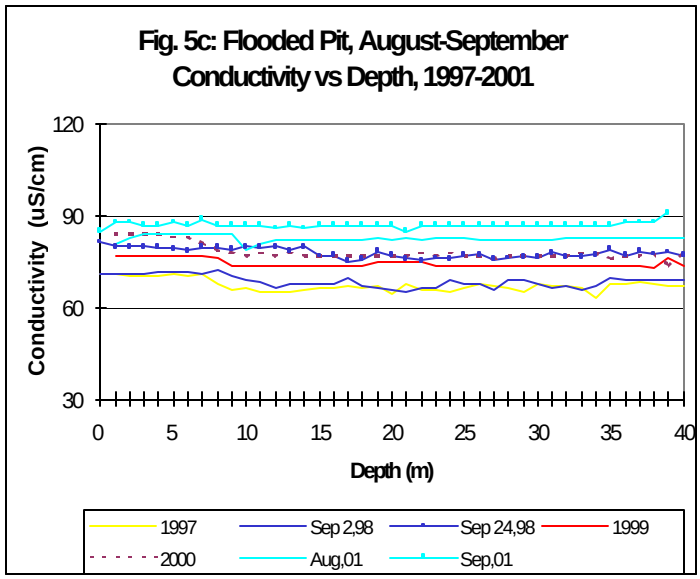


Fig. 5c: Flooded Pit, August-September
Conductivity vs Depth, 1997-2001
Conductivity (uS/cm)
120
90
60
30
0
5
10
15
20
25
30
35
40
Depth (m)
1997
Sep 2,98
Sep 24,98
1999
2000
Aug,01
Sep,01

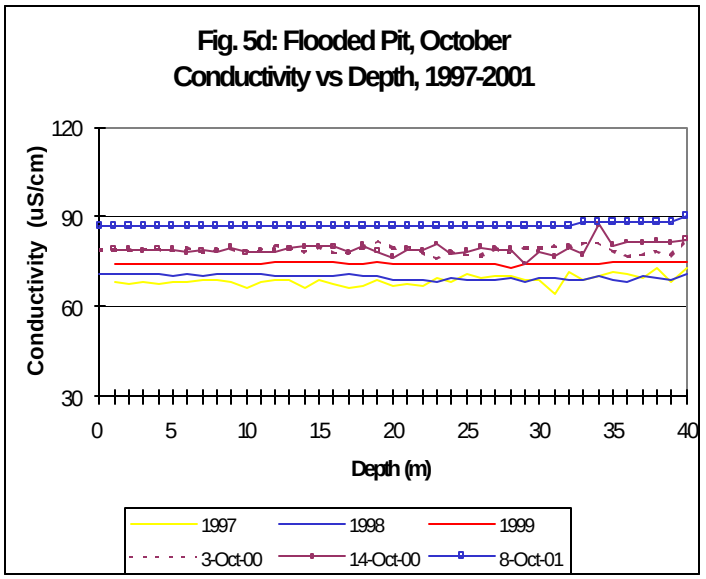


Fig. 5d: Flooded Pit, October
Conductivity vs Depth, 1997-2001
Conductivity (uS/cm)
120
90
60
30
0
5
10
15
20
25
30
35
40
Depth (m)
1997
1998
1999
3-Oct-00
14-Oct-00
8-Oct-01

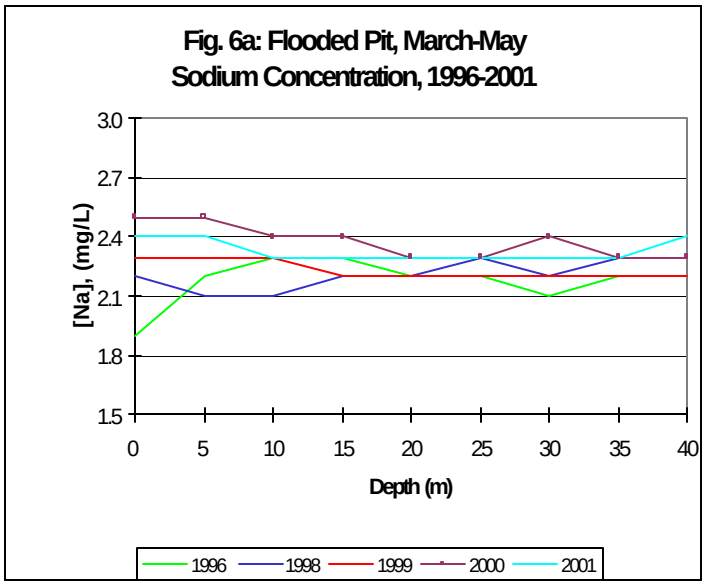


Fig. 6a: Flooded Pit, March-May
Sodium Concentration, 1996-2001
[Na], (mg/L)
3.0
2.7
2.4
2.1
1.8
1.5
0
5
10
15
20
25
30
35
40
Depth (m)
1996
1998
1999
2000
2001

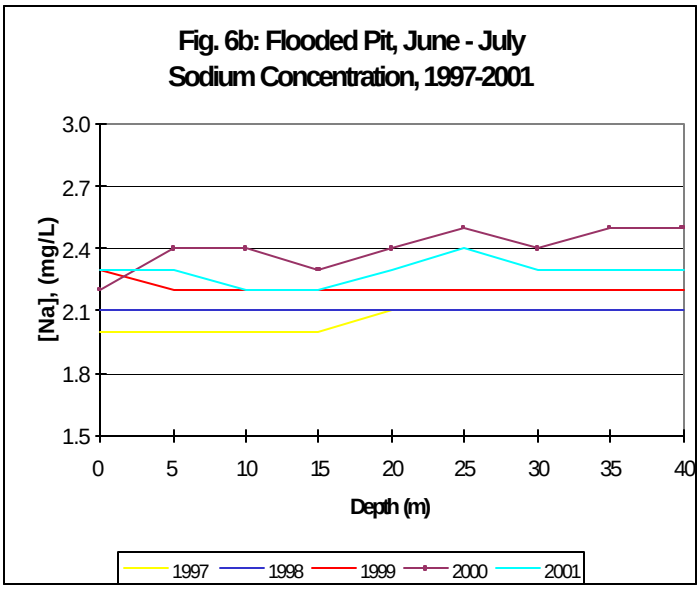


Fig. 6b: Flooded Pit, June - July
Sodium Concentration, 1997-2001
[Na], (mg/L)
3.0
2.7
2.4
2.1
1.8
1.5
0
5
10
15
20
25
30
35
40
Depth (m)
1997
1998
1999
2000
2001

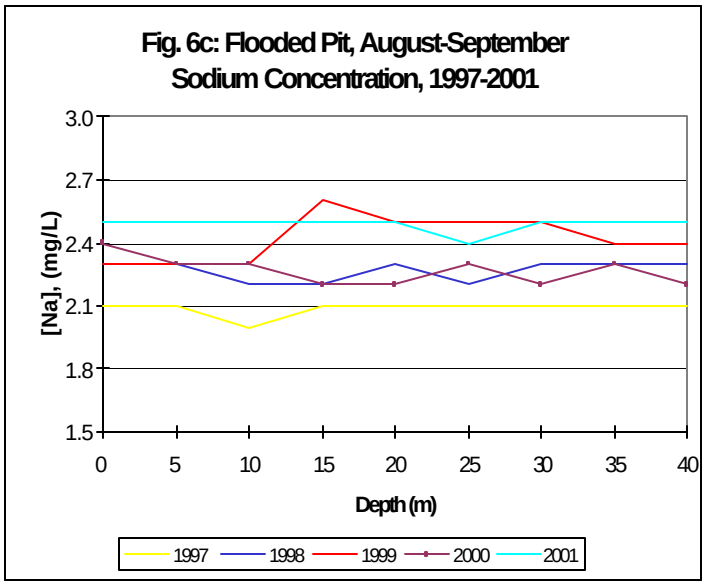


Fig. 6c: Flooded Pit, August-September
Sodium Concentration, 1997-2001
[Na], (mg/L)
3.0
2.7
2.4
2.1
1.8
1.5
0
5
10
15
20
25
30
35
40
Depth (m)
1997
1998
1999
2000
2001

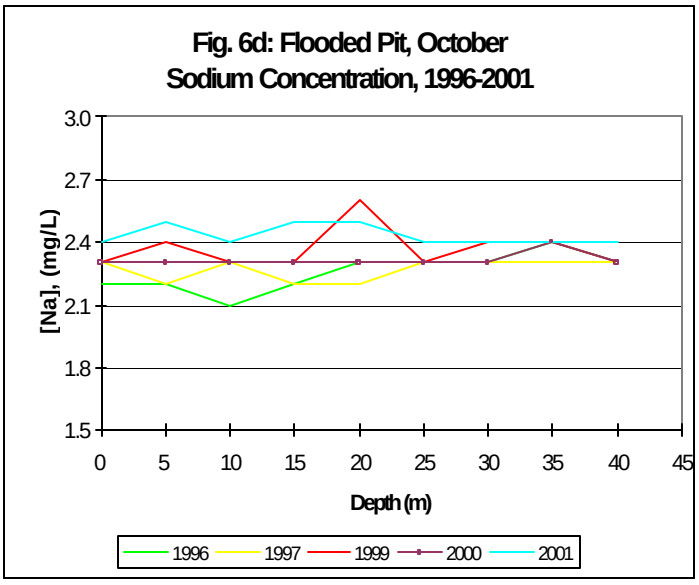


Fig. 6d: Flooded Pit, October
Sodium Concentration, 1996-2001
[Na], (mg/L)
3.0
2.7
2.4
2.1
1.8
1.5
0
5
10
15
20
25
30
35
40
45
Depth (m)
1996
1997
1999
2000
2001

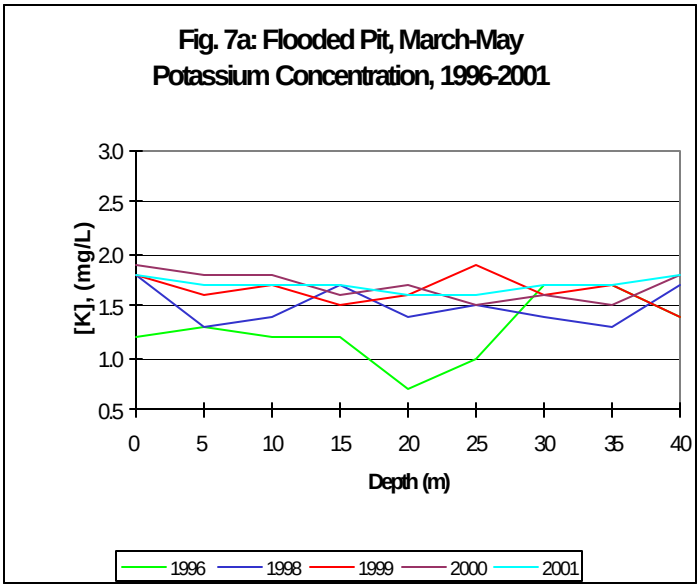


Fig. 7a: Flooded Pit, March-May
Potassium Concentration, 1996-2001
[K], (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0 5 10 15 20 25 30 35 40
Depth (m)
1996 1998 1999 2000 2001

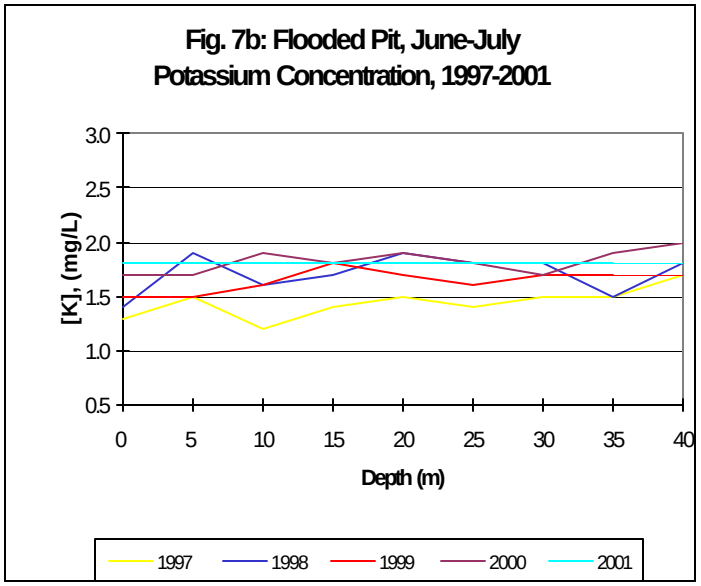


Fig. 7b: Flooded Pit, June-July
Potassium Concentration, 1997-2001
[K], (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0 5 10 15 20 25 30 35 40
Depth (m)
1997 1998 1999 2000 2001

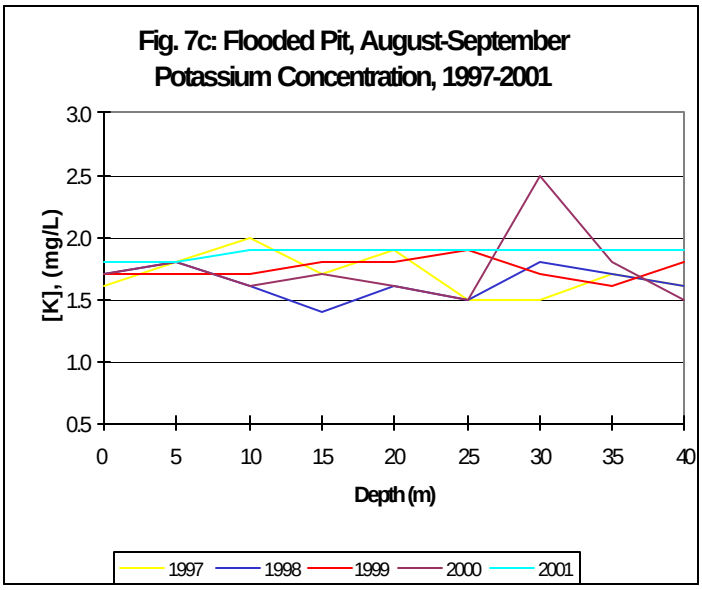


Fig. 7c: Flooded Pit, August-September
Potassium Concentration, 1997-2001
[K], (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0 5 10 15 20 25 30 35 40
Depth (m)
1997 1998 1999 2000 2001

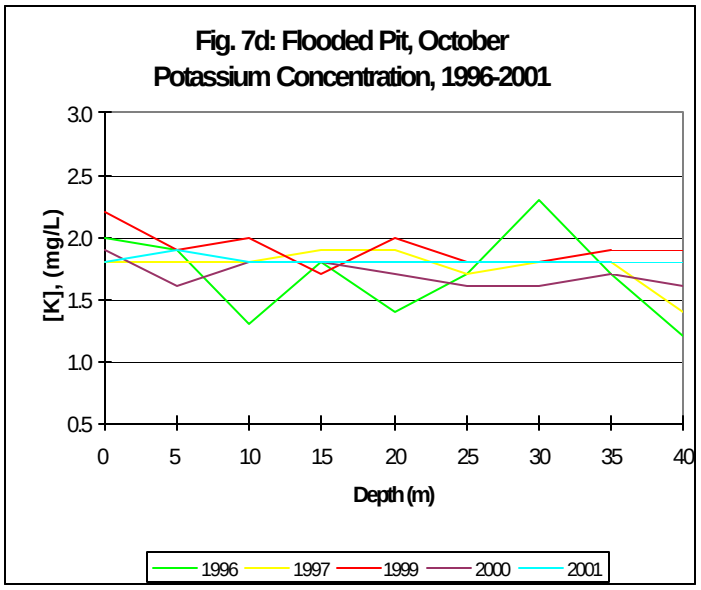


Fig. 7d: Flooded Pit, October
Potassium Concentration, 1996-2001
[K], (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0 5 10 15 20 25 30 35 40
Depth (m)
1996 1997 1999 2000 2001

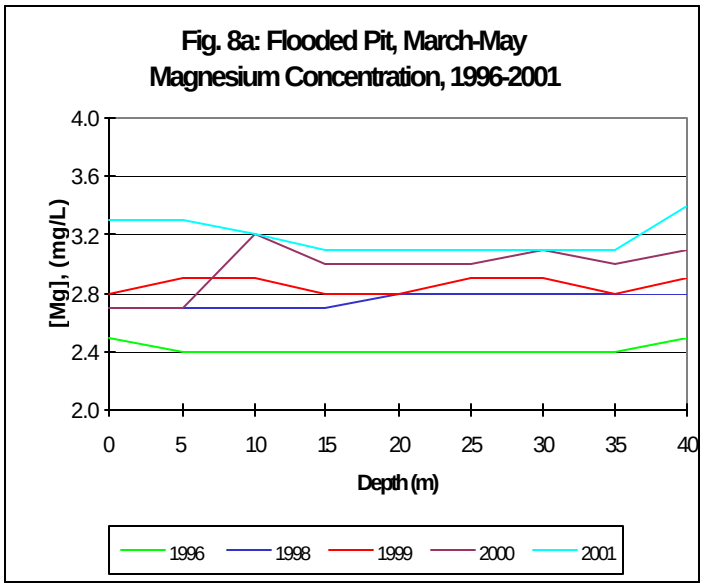


Fig. 8a: Flooded Pit, March-May
Magnesium Concentration, 1996-2001
[Mg], (mg/L)
4.0
3.6
3.2
2.8
2.4
2.0
0
5
10
15
20
25
30
35
40
Depth (m)
1996
1998
1999
2000
2001

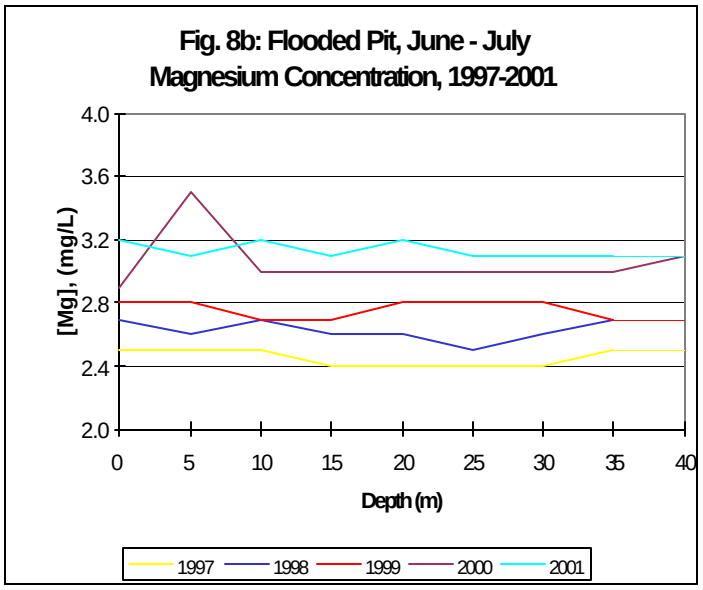


Fig. 8b: Flooded Pit, June - July
Magnesium Concentration, 1997-2001
[Mg], (mg/L)
4.0
3.6
3.2
2.8
2.4
2.0
0
5
10
15
20
25
30
35
40
Depth (m)
1997
1998
1999
2000
2001

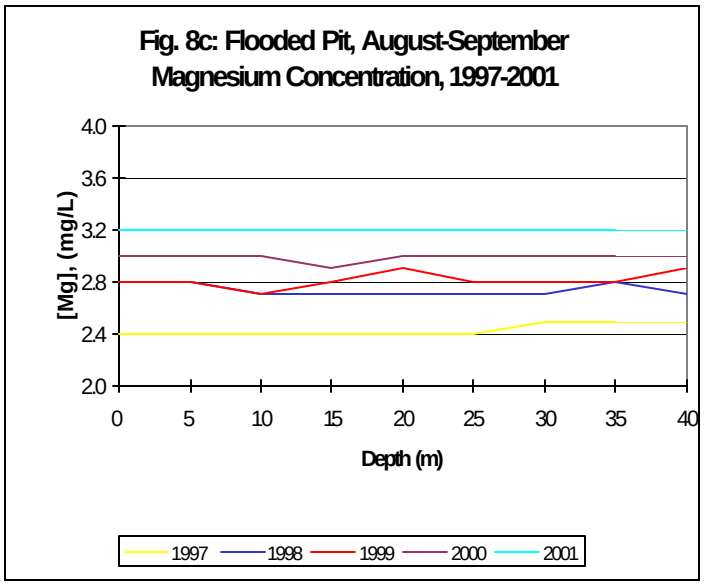


Fig. 8c: Flooded Pit, August-September
Magnesium Concentration, 1997-2001
[Mg], (mg/L)
4.0
3.6
3.2
2.8
2.4
2.0
0
5
10
15
20
25
30
35
40
Depth (m)
1997
1998
1999
2000
2001

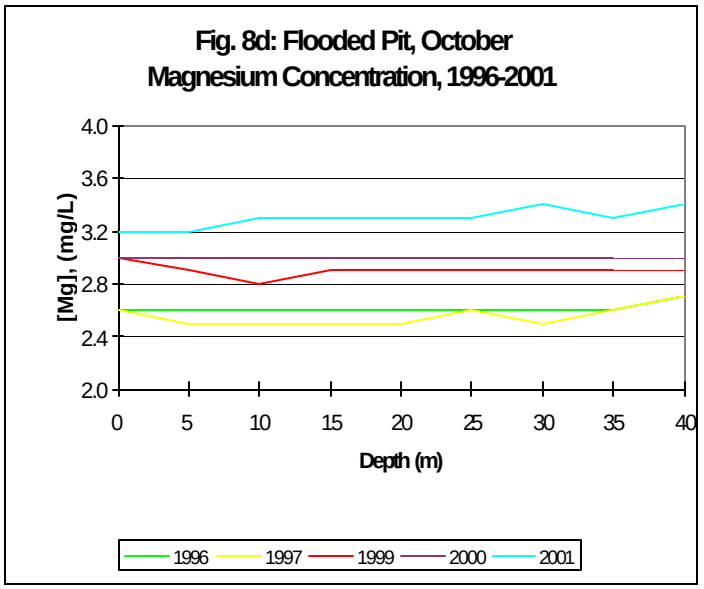


Fig. 8d: Flooded Pit, October
Magnesium Concentration, 1996-2001
[Mg], (mg/L)
4.0
3.6
3.2
2.8
2.4
2.0
0
5
10
15
20
25
30
35
40
Depth (m)
1996
1997
1999
2000
2001

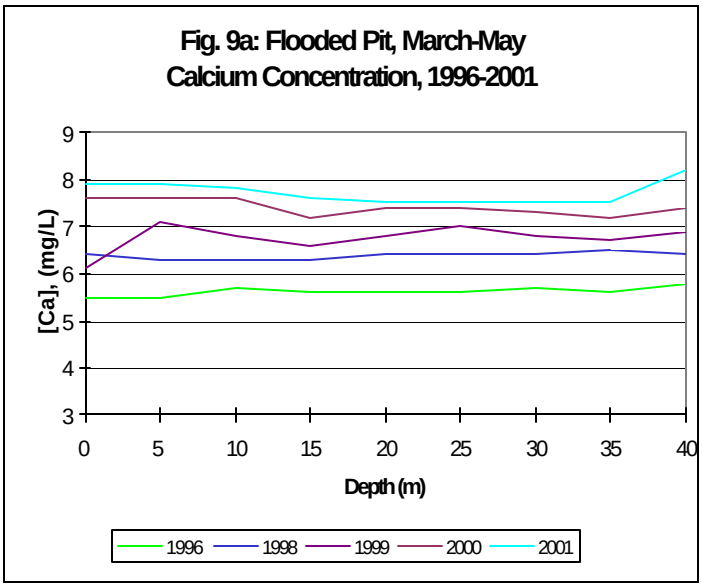


Fig. 9a: Flooded Pit, March-May
Calcium Concentration, 1996-2001
[Ca], (mg/L)
Depth (m)
1996
1998
1999
2000
2001

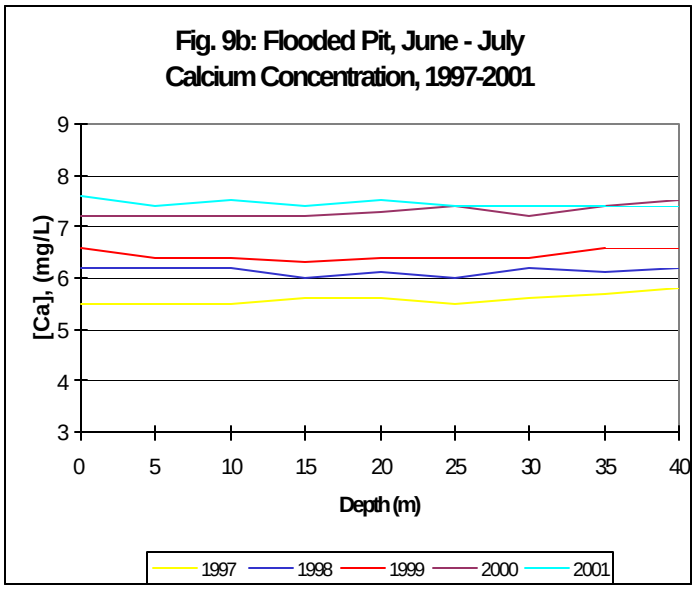


Fig. 9b: Flooded Pit, June - July
Calcium Concentration, 1997-2001
[Ca], (mg/L)
Depth (m)
1997
1998
1999
2000
2001

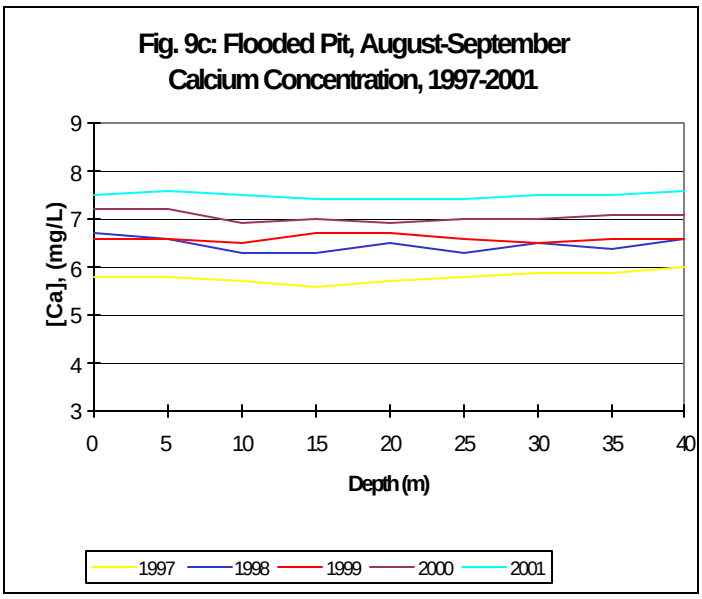


Fig. 9c: Flooded Pit, August-September
Calcium Concentration, 1997-2001
[Ca], (mg/L)
Depth (m)
1997
1998
1999
2000
2001

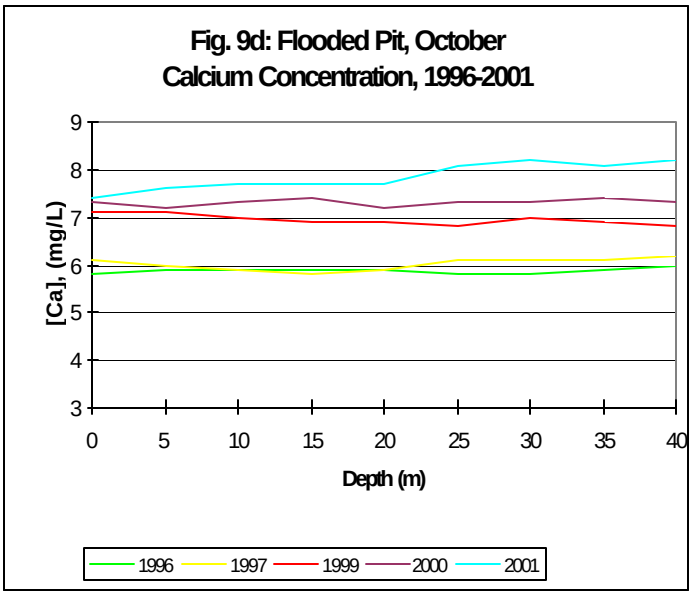


Fig. 9d: Flooded Pit, October
Calcium Concentration, 1996-2001
[Ca], (mg/L)
Depth (m)
1996
1997
1999
2000
2001

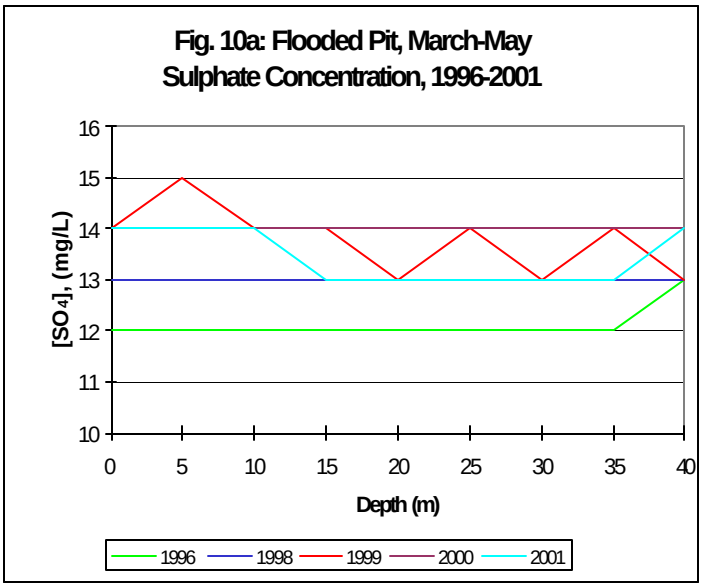


Fig. 10a: Flooded Pit, March-May
Sulphate Concentration, 1996-2001
[SO4], (mg/L)
16
15
14
13
12
11
10
0
5
10
15
20
25
30
35
40
Depth (m)
1996
1998
1999
2000
2001

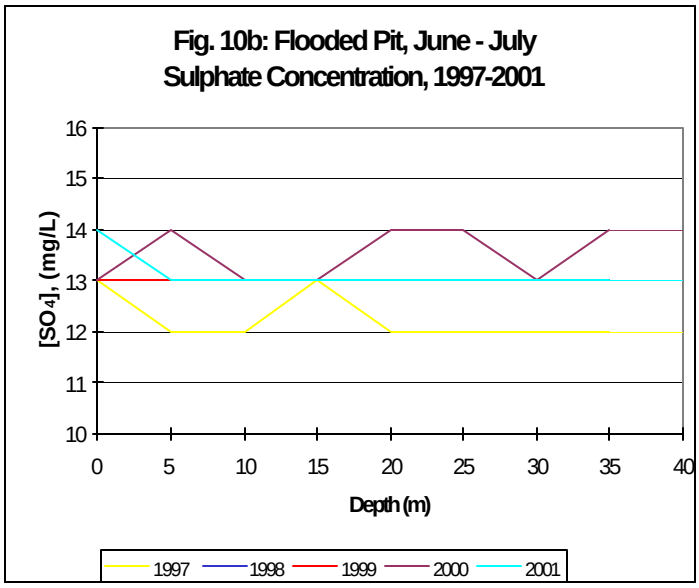


Fig. 10b: Flooded Pit, June - July
Sulphate Concentration, 1997-2001
[SO4], (mg/L)
16
15
14
13
12
11
10
0
5
10
15
20
25
30
35
40
Depth (m)
1997
1998
1999
2000
2001

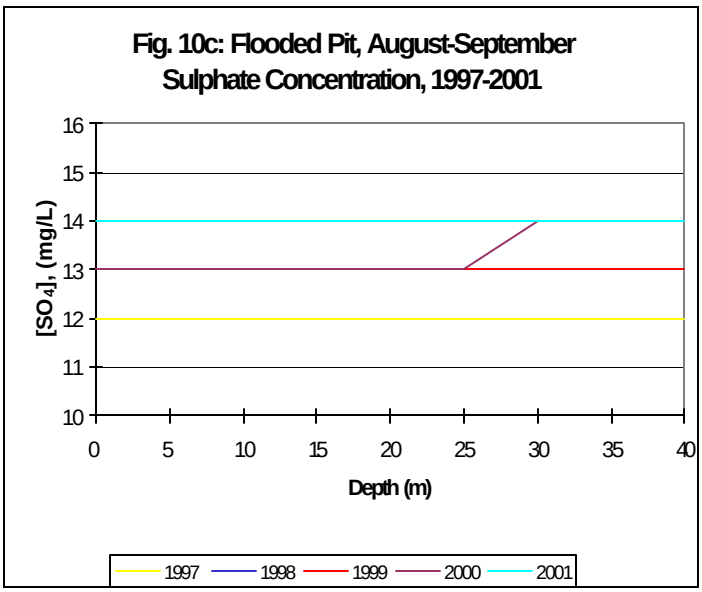


Fig. 10c: Flooded Pit, August-September
Sulphate Concentration, 1997-2001
[SO4], (mg/L)
16
15
14
13
12
11
10
0
5
10
15
20
25
30
35
40
Depth (m)
1997
1998
1999
2000
2001

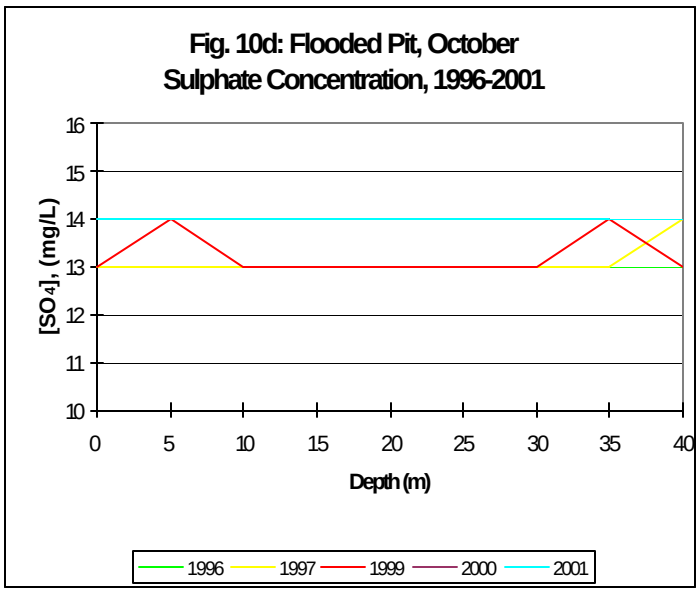


Fig. 10d: Flooded Pit, October
Sulphate Concentration, 1996-2001
[SO4], (mg/L)
16
15
14
13
12
11
10
0
5
10
15
20
25
30
35
40
Depth (m)
1996
1997
1999
2000
2001

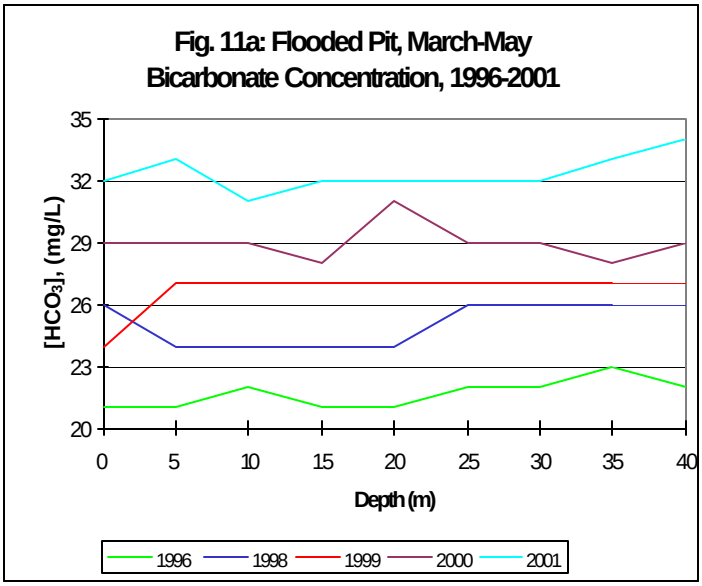


Fig. 11a: Flooded Pit, March-May
Bicarbonate Concentration, 1996-2001
[HCO3], (mg/L)
35
32
29
26
23
20
0
5
10
15
20
25
30
35
40
Depth (m)
1996
1998
1999
2000
2001

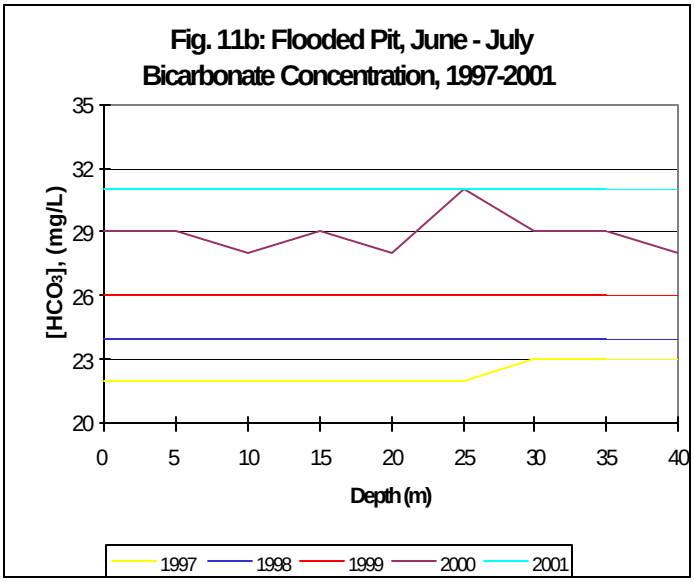


Fig. 11b: Flooded Pit, June - July
Bicarbonate Concentration, 1997-2001
[HCO3], (mg/L)
35
32
29
26
23
20
0
5
10
15
20
25
30
35
40
Depth (m)
1997
1998
1999
2000
2001

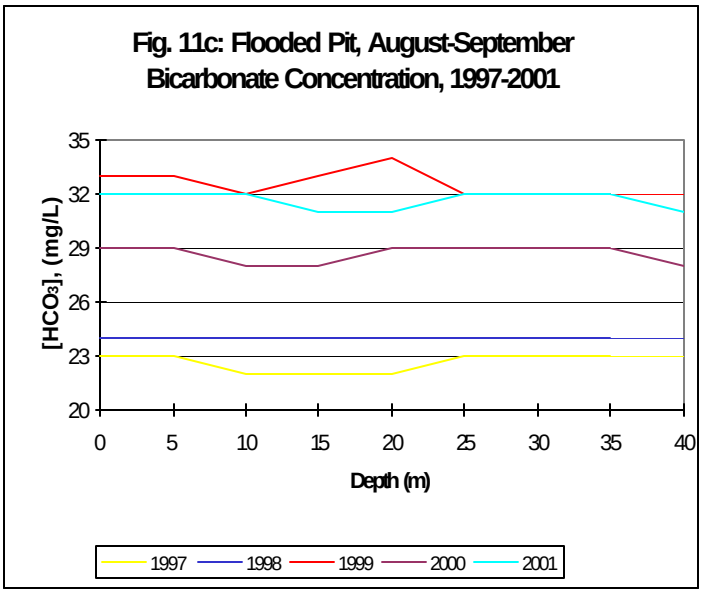


Fig. 11c: Flooded Pit, August-September
Bicarbonate Concentration, 1997-2001
[HCO3], (mg/L)
35
32
29
26
23
20
0
5
10
15
20
25
30
35
40
Depth (m)
1997
1998
1999
2000
2001

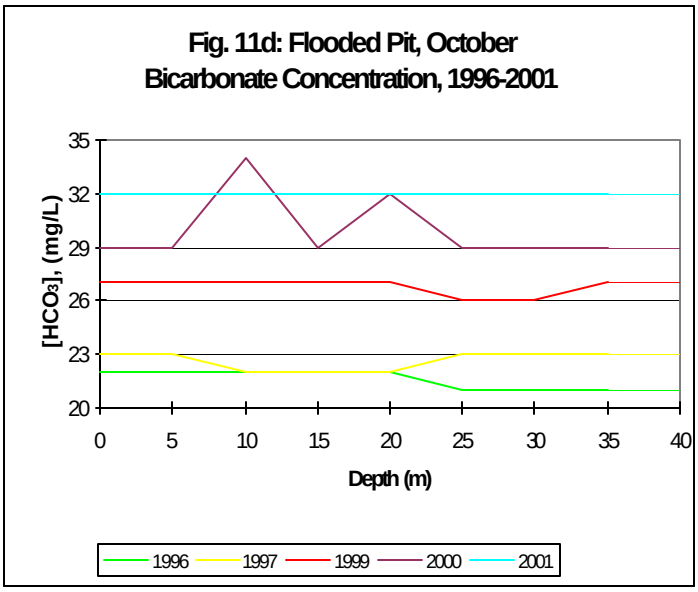


Fig. 11d: Flooded Pit, October
Bicarbonate Concentration, 1996-2001
[HCO3], (mg/L)
35
32
29
26
23
20
0
5
10
15
20
25
30
35
40
Depth (m)
1996
1997
1999
2000
2001

Fig. 12: Flooded Pit, 1997-2001 Data
PO_4 vs Depth

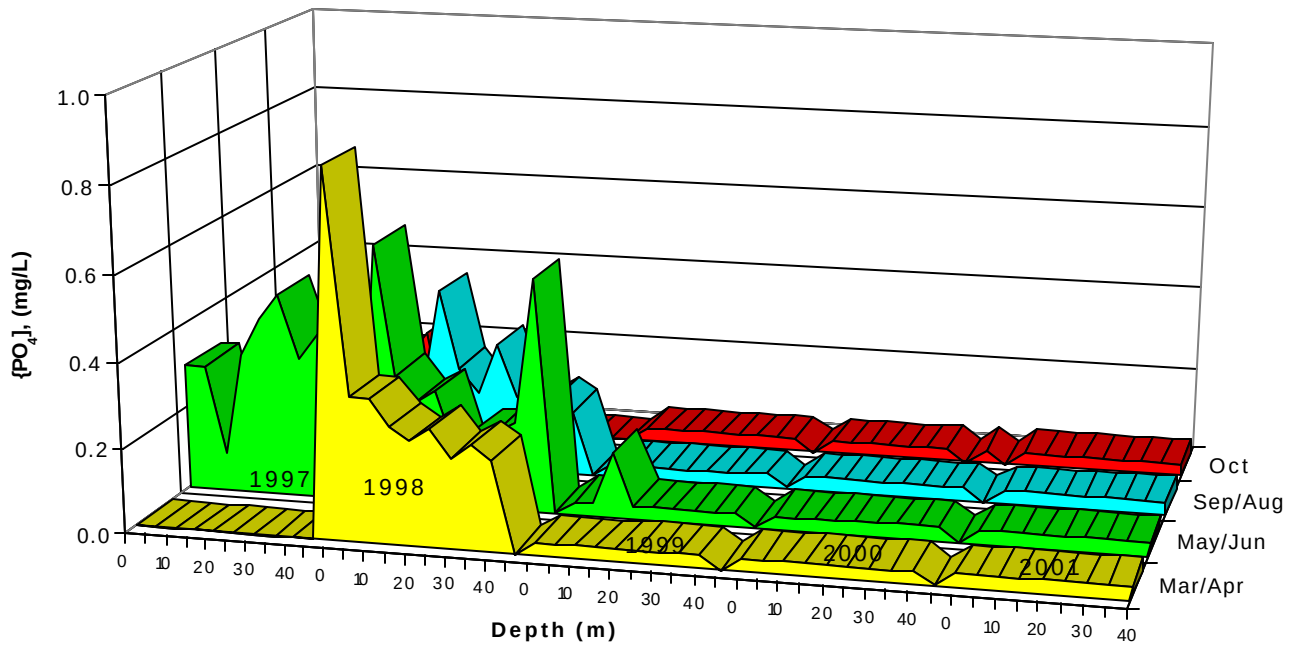


Fig. 13: Flooded Pit, 1997-2000 Data
NO_3 vs Depth

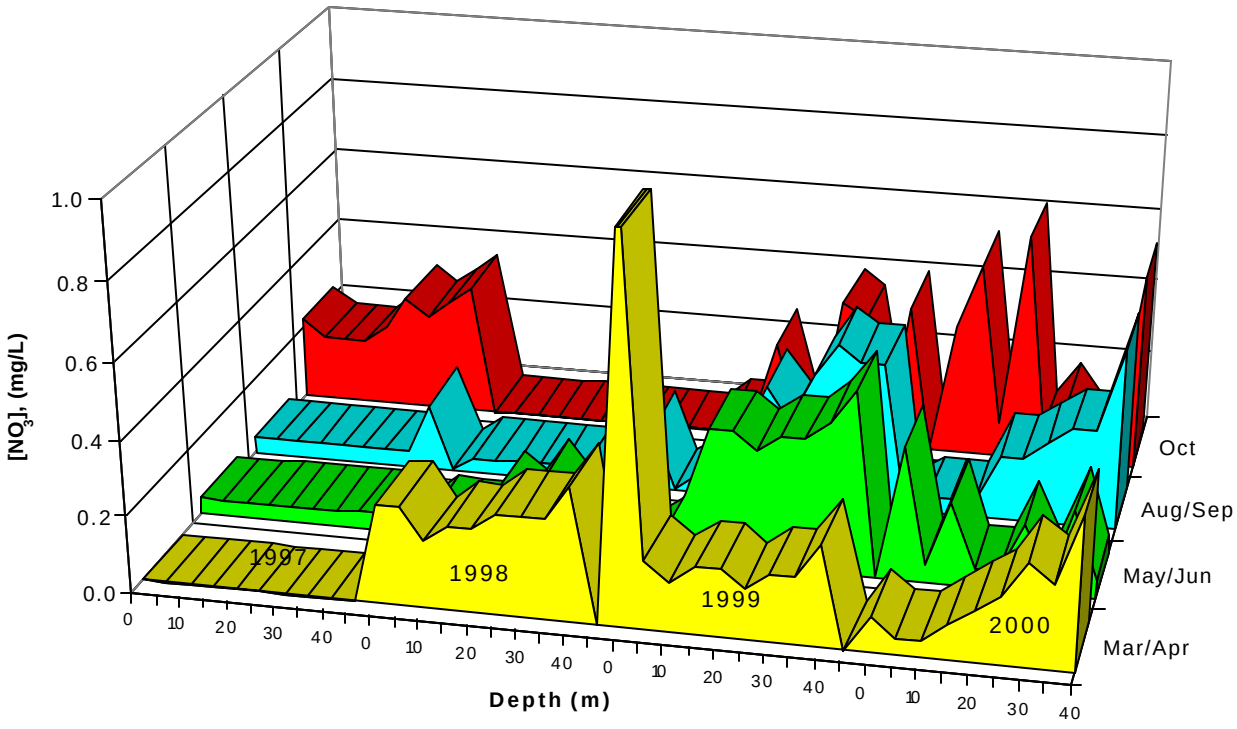


Fig. 14: Flooded Pit, 1997-2001 Data
NH_4 vs Depth

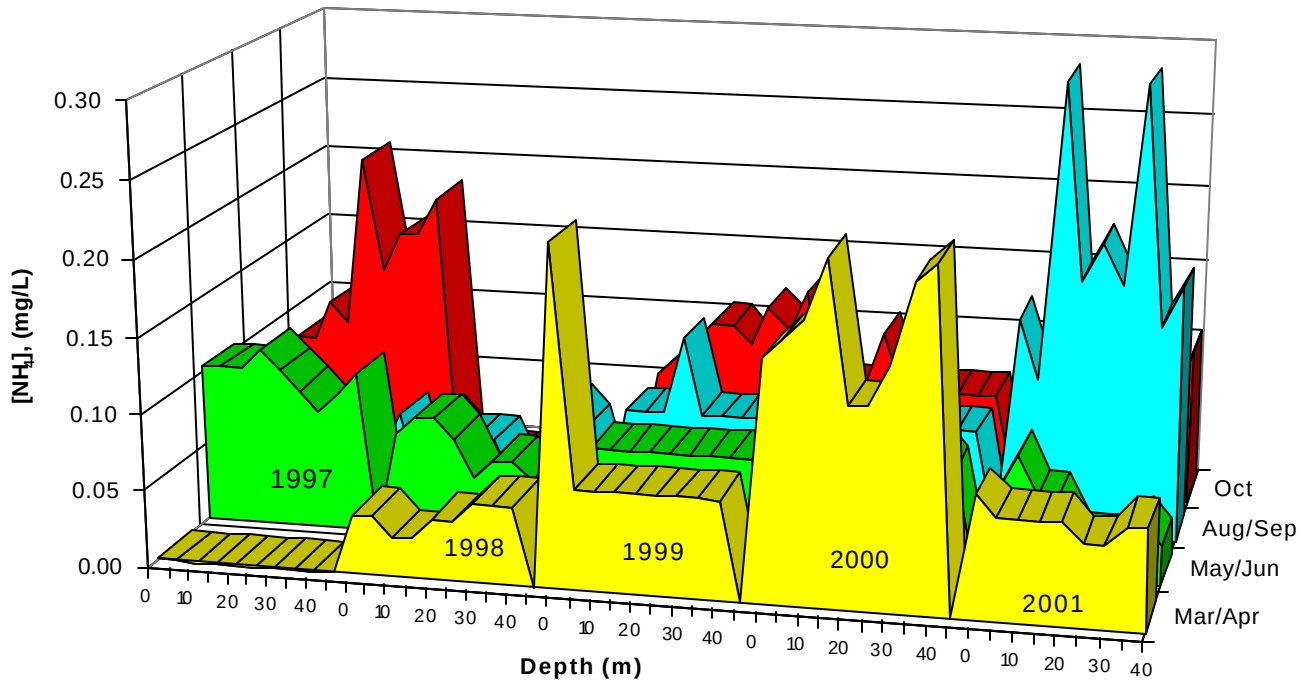


Fig. 15: Flooded Pit, 1997-2000 Data
Total Organic Carbon vs Depth

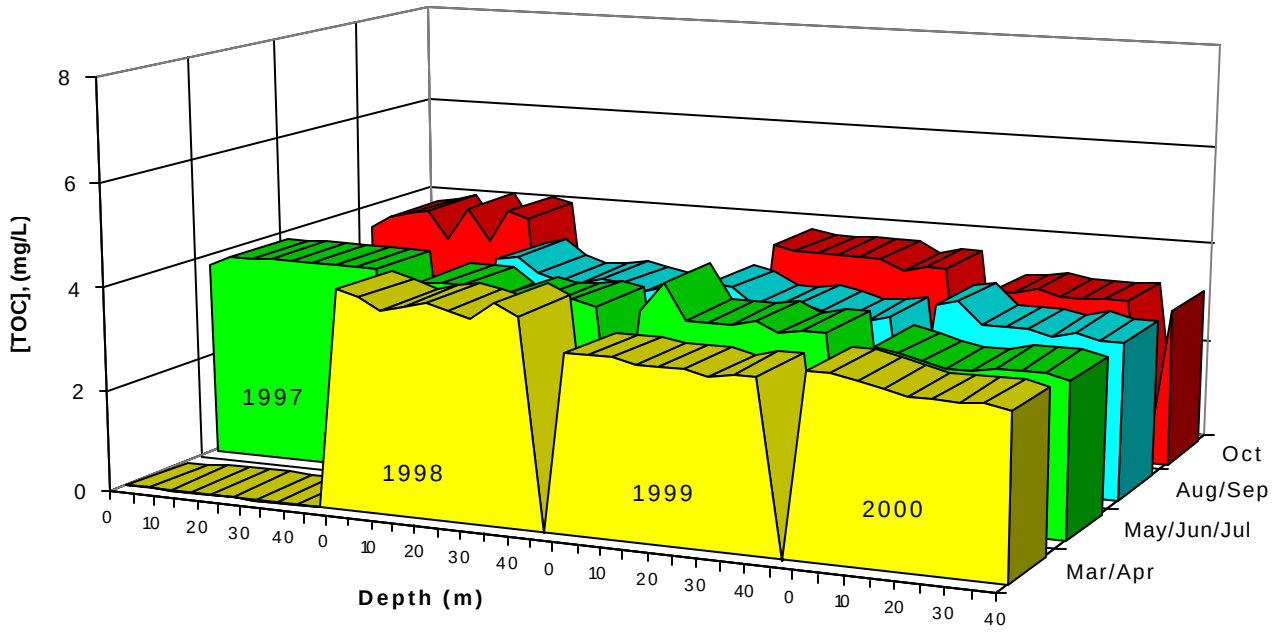
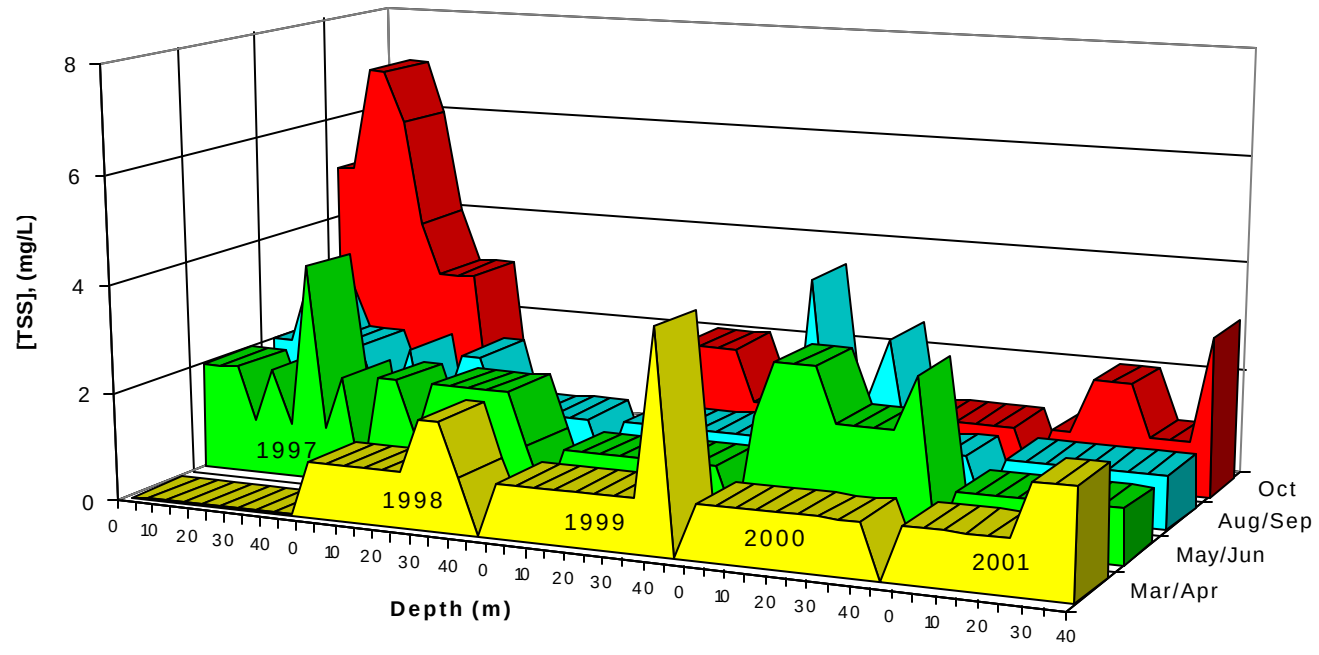


Fig. 16: Flooded Pit, 1997-2001 Data
Total Suspended Solids vs Depth



Appendix 3

Methods

TABLE OF CONTENTS

Sedimentation Trap Retrieval and Sampling

October 28, 1999

1.0 INTRODUCTION

A series of four sedimentation traps are located at Stn 6.72 in the B-Zone pit. These traps should be sampled prior to winter freeze-up. TWO PEOPLE AND GOOD GLOVES NEEDED. Sampling instructions are provided below.

2.0 MATERIALS

- 1/4" wood dowelling, 70 cm long, clean
- Large white "Kitchen Catcher" plastic bags
- 1.5 m of 0.7 to 1.0 cm I.D. clear flexible hose ***(Note 1:** using a smaller I.D. siphon will extend siphoning time; bigger I.D., poor control, sediment vacuumed out!)*
- 1 litre wide mouth plastic bottles
- Large clean plastic funnel

3.0 METHOD

a) Approach sedimentation trap float with boat very slowly such that, upon grasping the rope beneath the float (not the float itself), the boat comes to a halt by the weight of the sedimentation trap's anchor.

b) Haul each of the sedimentation traps up to the surface, making sure to clear the boat gunnel and not bang the trap into the boat. The trap's anchor will be cumbersome, and will make standing of the trap set-up upright difficult.

c) Take whole set of four traps to shore and work there.

d) Slowly insert the clear flexible hose into a tube of the trap until the hose is about 6 cm from the bottom. Drape the other end of the hose over the side of the boat. Definitively start the siphon by mouth and drain down the tube. Do not falter - if start-up of the siphon is unsuccessful, water in the plastic hose will backwash into the tube, disturbing the sediments into the tube's water column.

Note 2: *It is likely that there will be settled solids both on the bottom of each of the five tubes of the trap as well as on the inside of the walls of the tubes. The bottom sediment is the target, not the side sediments.*

Note 3: *In the event the siphon disturbs the bottom sediment, the entire volume of that tube will have to be sampled, not just the bottom 6 cm (i.e., large sample volume, multiple 1 litre sample bottles per sample, etc.).*

e) Repeat the siphoning procedure for all five tubes. There should now be five tubes with about 6 cm of water in each with sediment lying on bottom.

f) Using the wooden dowelling, agitate and scrape bottom of each tube to loosen all sediment.

g) Place kitchen catcher over all five mouths of the tubes. Violently swirl the entire sed trap - plastic bag set up, then invert in one fast move, such that content of all five tubes is dumped into plastic bag.

Note 4: *Hang onto the edges of that plastic bag - don't drop it as that water hits the bottom!*

h) Using the funnel, pour the water-sediment slurry from the plastic bag into the wide mouth plastic bottle and seal.

i) Wash the traps well with lake water, since mud will dry on, making cleaning that much more difficult later. Store traps in back of lab.

j) Keep samples cold during storage, as anaerobiosis and decay will rapidly set in.

4.0 DESCRIPTION, MEASUREMENTS AND ANALYSES

a) Sampling location, date, " Sed Trap Sample" notation

b) Colour, texture, smell

c) All five tubes sampled?

d) Send whole samples to Boojum

3.2 Sediment Extraction and Sample Preparation

3.2.1 Moisture content

Measured 60 mL sample and weighted to get wet weight for each sample. Placed the samples in a oven under 60 °C for 24 hours, which called air-dried sample. Weighed these air-dried samples to get air-dried weights.

The moisture content was obtained based on the following equation:

$$\text{Moisture Content (\%)} = \frac{\text{Wet Weight of 60mL Sample (g)} - \text{Dried Weight of 60mL Sample (g)}}{\text{Wet Weight of 60mL Sample (g)}} * 100$$

3.2.2 Wet Density

The sample density was calculated according to the following equation:

$$\text{Density (g/mL)} = \frac{\text{Wet Weight of 60mL Sample (g)}}{\text{60mL Volume of Sample (mL)}}$$

3.3.3 Sample Preparation for Analysis

Ground the air-dried samples and let them pass through a 1 mm sieve and then placed in

plastic sample bags for ICP-25 and non-distractive uranium analysis. The grab samples 1 and 3 from station 6.71 and grab 3 to 6 from station 6.72 were combined, respectively based on their corresponding depth and similarities in colour and texture.

Appendix 4

RAW DATA

LIST OF TABLES

LIST OF FIGURES AND PLATES

App4-Table 1: Descriptions of Sediment Samples Collected During June, 1999 Site Visit

Station 6.72			
Sample	dapth (cm)	Water level (m)	Sample Description
Grab 1	0-1		Loose red oxidized flocc/fine particles that appear to be settled iron oxides, (photo taken).
	1-2		Clearly varved. Light gray clay going down to medium clay, also containes a bit of 0-1cm layer.
	2-4		Loose olive grey unvarved material which is likely old phytoplankton.
	4-7		Medium grey elastic silty clay.
	>7		Original floor. Pinky fine solids which contain sand,gravel and silt.
Grab 2	0-0.2	43.5	Fine clay with a light brown film
	0.2-1		Orange iron hydroxide precipitate layer.
	1-1.4		Olive green layer.
	1.4-4		Light grey plastic silty clay layer.
	>4		no sample was collected due to Eckmann jaws being partly open.
Grab 3	0-1		Sample had 1mm top layer of light brown film and the underlayer was red/orange hydroxide.
	1-1.5		Olive green,loose, very fine, organic.
	1.5-4		Light grey plastic, no varving, silty clay.
Grab 4	0-1	44.2	Sample was mixed by sampling method.Contained a light brown film and a red hydroxide layer.
	1-2		Olive green loose, very fine, organic. A very fine film between this layer and the next. This film has black streaks which are probaly sulfides and reduced cpmpounds
	2-6		Light grey, plastic, silty clay, gravel on bottom of Eckmann.
Grab 5	0-1	43.5	Thin light brown 2mm film on top of orange hydroxide.Photo taken before and after removal of top layer.
	1-2.5		A mixture of olive green and black with amber curds scattered in layer.
	2.5-5.5		Light grey, plastic silty layer.
Grab 6	0-1	43	Light brown 0.8mm thin top layer followed by a under layer of orange hydroxide.
	1-2.8		Olive green, loose, very fine organic layer.
	2.8-5.8		Light grey, plastic silty clay.
Station 6.71			
Grab 1	0-0.5	41.5	Top layer was somewhat mixed with light brown and orange hydroxide. Also sample was very loose.
	0.5-1.5		Olive green and black mixture (black was more evenly diseminated than the others that had streaks of black), sample also contained yellow specks.
	1.5-5.5		Light grey plastic silty clay. No gravel seen in bottom of sample.
Grab 2	0-0.5	41.25	Very loose mixture (by sampling method) of light brown and orange hydroxide layer.
	0.5-3.0		Olive green, loose organic layer, black material quite abundant.
	3.0-3.5		Layer of peat, root mass over top of clay. This may have been washed down into the pit during flooding.
	3.5-6.0		Light gray silty plastic clay. No gravel noted.
Grab 3	0-0.8	41.1	Light brown thin layer on top of orange hydroxide layer.
	0.8-2.3		Olive green, black (less than Grab 2) loose organic. Sample is more clayier and stiffer than other olive green samples.
	2.3-6.3		Light grey, plastic silty clay. No gravel seen in sample.
B-Zone Pit Perimeter Road Fill*	0-0.1	1	turquoise evaporites in light beige fine sand
	0.1-1	1	light beige moist fine sand

App4-Table 2: Moisture Content of Solid Samples from June, 1999 Site Visit

Stn	Water Level	Sample type	Depth (cm)	Wet Vol (ml)	Wet wt.(g)	Dry wt (g)	Wet Density (g/mL)	Moisture (%)
6.72	nm	Grab 1	0-1	40.00	33.05	7.41	0.826	77.58
	nm	Grab 1	1-2	60.00	50.48	10.13	0.841	79.93
	nm	Grab 1	2-4	60.00	50.56	7.17	0.843	85.82
	nm	Grab 1	4-7	60.00	80.71	51.78	1.345	35.84
	nm	Grab 3	0-1	20.00	23.24	5.95	1.162	74.40
	nm	Grab 3	1-1.5	60.00	58.48	13.05	0.975	77.68
	nm	Grab 3	1.5-4	60.00	86.27	56.77	1.438	34.19
	44.2 m	Grab 4	0-1	20.00	14.54	3.20	0.727	77.99
	44.2 m	Grab 4	1-2	60.00	58.61	14.05	0.977	76.03
	44.2 m	Grab 4	2-6	60.00	78.31	51.03	1.305	34.84
	43.5 m	Grab 5	0-1	60.00	48.43	11.88	0.807	75.47
	43.5 m	Grab 5	1-2.5	60.00	57.38	6.50	0.956	88.67
	43.5 m	Grab 5	2.5-5.5	60.00	90.35	58.99	1.506	34.71
	43 m	Grab 6	0-1	60.00	57.72	12.40	0.962	78.52
	43 m	Grab 6	1-2.8	60.00	59.65	8.38	0.994	85.95
	43 m	Grab 6	2.8-5.8	60.00	91.52	60.70	1.525	33.68
6.71	41.5 m	Grab 1	0-0.5	60.00	56.49	10.90	0.942	80.70
	41.5 m	Grab 1	0.5-1.5	60.00	57.00	7.31	0.950	87.18
	41.5 m	Grab 1	1.5-5.5	60.00	80.29	50.68	1.338	36.88
	41.25 m	Grab 2	0-0.5	60.00	60.40	10.30	1.007	82.95
	41.25 m	Grab 2	0.5-3	60.00	62.71	14.29	1.045	77.21
	41.25 m	Grab 2	3-3.5	60.00	61.96	21.78	1.033	64.85
	41.25 m	Grab 2	3.5-6	60.00	86.07	53.53	1.435	37.81
	41.1 m	Grab 3	0-0.8	60.00	73.10	18.50	1.218	74.69
	41.1 m	Grab 3	0.8-2.3	60.00	63.29	20.38	1.055	67.80
	41.1 m	Grab 3	2.3-6.3	60.00	83.77	53.06	1.396	36.66
6.72	2 m	Sed trap	nm	60.00	57.31	0.34	0.955	99.41
	12 m	Sed trap	nm	60.00	57.61	2.64	0.960	95.42
	22 m	Sed trap	nm	60.00	56.74	2.80	0.946	95.07
	32 m	Sed trap	nm	60.00	57.05	2.34	0.951	95.90
Stn 100	0.5 m	Sed trap	nm	60.00	56.85	2.78	0.948	95.11
Stn 250	0.5 m	Sed trap	nm	60.00	57.35	4.68	0.956	91.84
Peri Road Fill Plot #2	surface	hand scrape	0-0.5 cm	60.00	59.80	37.08	0.997	37.99
Peri Road Fill Plot #1	surface	hand scrape	0-0.2 cm	60.00	31.44	29.52	0.524	6.11

App4-Table 3: Sample Combination and Uranium Concentration, 1999

Location	Sampling Site	Depth (cm)	Description	Uranium (ug/g)
6.72	Grab 1	0-1	Loose Red oxidized flocc/fine particles that settled as iron oxides	272
		1-2	Light gray clay going down to medium clay, also containes a bit of layer 0-1 cm.	315
		2-4	Loose olive gray unvarved material which is likely old plankton	279
		4-7	Medium gray elastic silty clay	112
	Grab 3 to 6 combined	0-1	top layer of a light brown film and lower layer of red hydroxide layer	290
		1-2	olive green loose and very fine organics.	265
		2-6	light gray plastic silty layer.	116
6.71	Grab 1 and 3 combined	0-0.5	light brown thin top layer with a layer of iron hydroxide underneath	236
		0.5-2.3	Olive green and black mixture	228
		2.3-6.3	light gray plastic silty layer.	108
	Grab 2	0-0.5	Very loose mixture of light brown and red hydroxide layer	242
		0.5-3.0	Olive green, loose organic layer , black material quite abundant.	252
		3.0-3.5	Layer of peat, root mass over top of clay	123
		3.5-6.0	Light gray silty plastic clay. No gravel noted	117
Perimeter Road	Fill Plot #1	0-0.2	Blue green. Nickle oxide evaporate	82.2
	Fill Plot #2	0-0.5	Blue green. Nickle oxide evaporate	143

App4-Table 4. Ekman Dredge Sediment Analysis

	Stn 6.71 26-Aug-97 Upper Layer	Stn 6.71 Middle Layer		Stn 6.72 24-Aug-97 Layer 1	Stn 6.72 24-Aug-97 Layer 2	Stn 6.72 24-Aug-97 Layer 3	Stn 6.72 24-Aug-97 Layer 4
Field Description				Fine black-olive sediment	Gelatenous olive sediment	Loose gray clay	Fine white sand
Lab Description	Very moist yellow to gray very fine silt	Very moist tan brown very fine clay		Very moist light brown sediment	Very moist light brown fine silt and sediment	Very moist light brown fine silt and sediment	
Stratum (cm)	0 - 3 cm	3 - 8 cm		0-1.5 cm	1.5-3 cm	3-8 cm	> 8 cm
Subsample Wet Vol., mL	60	60		60	60	60	
Wet Wt., g	66	89		65	87	90	
Dry wt., g	16	55		11	36	57	
Moisture Content, %	76	38		83	59	37	
Dry sediment [As] $ug.g^{-1}$	1,100	110		1,500	440	210	
Dry sediment [Ni] $ug.g^{-1}$	550	180		820	420	230	
m3 $sediment.m^{-2}$	0.030	0.050		0.015	0.015	0.050	
g $dry\ sediment.m^{-2}$	7,800	45,917		2,725	8,875	47,167	
g $As.m^{-2}$ sediment	8.6	5.1		4.1	3.9	9.9	
g $Ni.m^{-2}$ sediment	4.3	8.3		2.2	3.7	11	
Sediment surface area, m^2	333,557	333,557		333,557	333,557	333,557	
50 % Sediment surface area, m^2	166,779	166,779		166,779	166,779	166,779	
			SUM				**SUM**
kg As in sediment layer	1,431	842	**2,273**	682	651	1,652	**2,985**
kg Ni in sediment layer	715	1,378	**2,094**	373	622	1,809	**2,804**

App4-Table 5: Results of Analyses of B-Zone Pit S-W Perimeter Road Surface Samples 1993 (B-Zone WRP Drilling), 1997 (M. Baldero, Cameco) and 1999 (Boojum)

Sample Name	Stratum Sampled	Date Sampled	As mg.kg^{-1}	Ni mg.kg^{-1}	S mg.kg^{-1}	U mg.kg^{-1}	Fe mg.kg^{-1}
A: S-W Road Bed Wasterock Sampled By M.Baldero,Cameco, June, 1997							
B/Z 1		22-Jun-97	138	168	210	610	N.M.
B/Z 2		22-Jun-97	226	246	720	1,050	N.M.
B/Z 3		22-Jun-97	135	87	340	340	N.M.
B/Z 4		22-Jun-97	160	99	370	300	N.M.
B/Z 5		22-Jun-97	545	410	180	1,090	N.M.
B/Z 6		22-Jun-97	166	82	410	330	N.M.
B/Z 7		22-Jun-97	208	517	520	390	N.M.
B/Z 8		22-Jun-97	268	229	139	460	N.M.
B/Z 9		22-Jun-97	480	396	1,300	810	N.M.
B/Z 10		22-Jun-97	264	173	310	190	N.M.
B/Z 11		22-Jun-97	3,250	1,649	290	620	N.M.
B/Z 12		22-Jun-97	7,067	7,322	850	610	N.M.
B/Z 13		22-Jun-97	1,046	527	320	330	N.M.
B/Z 14		22-Jun-97	10,807	4,746	290	220	N.M.
B/Z 15		22-Jun-97	596	356	440	350	N.M.
B/Z 16		22-Jun-97	809	420	230	440	N.M.
B/Z 17		22-Jun-97	348	171	200	420	N.M.
B/Z 18		22-Jun-97	157	104	200	220	N.M.
min			135	82	139	190	
max			10,807	7,322	1,300	1,090	
average			**1,482**	**983**	**407**	**488**	
n			18	18	18	18	

B: B-Zone WRP 1993 Solid Samples Analyses: Summary from 1996 Boojum report,Table 12a.	As mg.kg^{-1}	Ni mg.kg^{-1}	S mg.kg^{-1}	U mg.kg^{-1}	Fe mg.kg^{-1}
min	1	6	200	5	2,800
max	2,760	1,800	4,600	539	43,300
average	**69**	**90**	**302**	**69**	**10,693**
n	97	97	97	97	97

C: Road Bed Surface Evaporite Samples Collected June 20, 1999 by Boojum personnel			As mg.kg^{-1}	Ni mg.kg^{-1}	S mg.kg^{-1}	U mg.kg^{-1}	Fe mg.kg^{-1}	Moisture %
B-Zone Pit Perimeter Road Fill Sample 1	0-0.1 cm	20-Jun-99	140	14,700			N.M.	15
	0.1 - 1 cn	20-Jun-99	70	2,700			N.M.	11

D: Filtered Slurry Supernatants of Surface Evaporite Samples Collected June 20, 1999 *			As mg.L^{-1}	Ni mg.L^{-1}	Fe mg.kg^{-1}	pH	Cond uS.cm^{-1}	T C
B-Zone Pit Perimeter Road Fill Sample 1	0-0.1 cm	20-Jun-99	1.72	1,530	N.M.	5.2	11920	25
	0.1 - 1 cm	20-Jun-99	0.72	240	N.M.	5.1	2880	25

* 10 g of dried sample slurried with 100 mL of distilled de-ionized water for 1 minute. Solids allowed to settle . Supernatant filtered from 0.45 um filter.

E: S-W Road Bed, Run-Off Event Water Samples, June 23, 1999.	Assay No.	As mg.L^{-1}	Ni mg.L^{-1}	S mg.L^{-1}	U mg.L^{-1}	Fe mg.L^{-1}	^{226}Ra Bq.L^{-1}
R/O into Pit	8167	0.46	26	260	0.14	0.061	7.8
R/O Puddle	8168	0.86	9.1	130	0.23	0.082	3.8
Road R/O Puddle	8169	0.34	44	320	0.17	0.79	6.5

App4-Table 6a : Thermocline Depth and Nickel Concentration in B-Zone Pit, 1995-1999.

Year	Date	Thermocline	Ni Concentration (mg/L)		
		(m)	Avg 0-5 m	20 m	Difference
1995	12-Apr	No	0.285	0.260	-0.025
	14-Jun	3	0.235	0.290	0.055
	17-Aug	10	0.175	0.260	0.085
	14-Oct	20	0.240	0.240	0.000
1996	09-May	No	0.280	0.270	-0.010
	26-Aug	9	0.220	0.290	0.070
	28-Oct	No	0.270	0.270	0.000
1997	Mar-Apr		NOT AVAILABLE		
	29-Jun	6	0.215	0.260	0.045
	12-Aug	8	0.215	0.260	0.045
	06-Oct	23	0.230	0.240	0.010
1998	18-Apr	No	0.245	0.240	-0.005
	01-Jun	No	0.230	0.250	0.020
	02-Sep	10	0.180	0.250	0.070
1999	17-Apr	No	0.225	0.230	0.005
	18-Jun	No	0.210	0.220	0.010
	10-Aug	8	0.180	0.220	0.040
	03-Oct	23	0.195	0.200	0.005

App4-Table 6b : Thermocline Depth and Arsenic Concentration in B-Zone Pit, 1995-1999.

Year	Date	Thermocline	As Concentration (mg/L)		
		(m)	Avg 0-5 m	20 m	Difference
1995	12-Apr	No	0.270	0.220	-0.050
	14-Jun	3	0.257	0.192	-0.065
	17-Aug	10	0.265	0.220	-0.045
	14-Oct	20	0.145	0.240	0.095
1996	09-May	No	0.230	0.190	-0.040
	26-Aug	9	0.195	0.210	0.015
	28-Oct	No	0.210	0.210	0.000
1997	Mar-Apr		NOT AVAILABLE		
	29-Jun	6	0.135	0.140	0.005
	12-Aug	8	0.150	0.130	-0.020
	06-Oct	23	0.120	0.120	0.000
1998	18-Apr	No	0.104	0.061	-0.043
	01-Jun	No	0.089	0.082	-0.006
	02-Sep	10	0.066	0.058	-0.008
1999	17-Apr	No	0.051	0.024	-0.027
	18-Jun	No	0.049	0.058	0.009
	10-Aug	8	0.044	0.027	-0.017
	03-Oct	23	0.030	0.031	0.002

App4-Table 6c: Thermocline Depth and Iron Concentration in B-Zone Pit, 1995-1999.

Year	Date	Thermocline	As Concentration (mg/L)		
		(m)	Avg 0-5 m	20 m	Difference
1995	12-Apr	No	0.335	0.510	0.175
	14-Jun	3	0.465	0.500	0.035
	17-Aug	10	0.435	0.510	0.075
	14-Oct	20	0.465	0.550	0.085
1996	09-May	No	0.390	0.460	0.070
	26-Aug	9	0.270	0.330	0.060
	28-Oct	No	0.325	0.340	0.015
1997	Mar-Apr		NOT AVAILABLE		
	29-Jun	6	0.220	0.250	0.030
	12-Aug	8	0.170	0.240	0.070
	06-Oct	23	0.300	0.270	-0.030
1998	18-Apr	No	0.160	0.420	0.260
	01-Jun	No	0.280	0.320	0.040
	02-Sep	10	0.115	0.310	0.195
1999	17-Apr	No	0.150	0.370	0.220
	18-Jun	No	0.285	0.350	0.065
	10-Aug	8	0.140	0.410	0.270
	03-Oct	23	0.300	0.300	0.000

App4-Table 6d: Thermocline Depth and Aluminum Concentration in B-Zone Pit, 1995-1999.

Year	Date	Thermocline	Al Concentration (mg/L)		
		(m)	Avg 0-5 m	20 m	Difference
1995	12-Apr	No	0.150	0.150	0.000
	14-Jun	3	0.296	0.240	-0.056
	17-Aug	10	0.355	0.280	-0.075
	14-Oct	20	0.270	0.390	0.120
1996	09-May	No	0.135	0.120	-0.015
	26-Aug	9	0.140	0.077	-0.063
	28-Oct	No	0.079	0.082	0.004
1997	Mar-Apr		NOT AVAILABLE		
	29-Jun	6	0.105	0.061	-0.044
	12-Aug	8	0.105	0.047	-0.058
	06-Oct	23	0.210	0.210	0.000
1998	18-Apr	No	0.048	0.042	-0.006
	01-Jun	No	0.070	0.071	0.001
	02-Sep	10	0.044	0.025	-0.019
1999	17-Apr	No	0.021	0.013	-0.008
	18-Jun	No	0.060	0.061	0.001
	10-Aug	8	0.036	0.015	-0.021
	03-Oct	23	0.034	0.038	0.004

App4-Table 6e: Thermocline Depth and pH in B-Zone Pit,

1995-1999.

Year	Date	Thermocline	pH (units)		
		(m)	0 or 1 m	5 m	20 m
1995	12-Apr	No	6.83	6.84	6.58
	14-Jun	3	7.75	7.22	6.51
	17-Aug	10	8.07	7.37	6.55
	14-Oct	20	6.87	6.91	6.70
1996	09-May	No	6.84	6.75	6.72
	26-Aug	9	7.47	7.42	6.58
	28-Oct	No	6.74	6.73	6.70
1997	Mar-Apr		NOT AVAILABLE		
	29-Jun	6	7.28	7.45	6.83
	12-Aug	8	7.06	7.38	7.58
	06-Oct	23	7.12	7.29	7.38
1998	18-Apr	No	7.04	7.07	6.89
	01-Jun	No	7.15	7.12	6.84
	02-Sep	10	5.78	6.14	6.40
1999	17-Apr	No	6.71	6.91	6.75
	18-Jun	No	6.84	6.92	6.76
	10-Aug	8	8.23	8.24	7.77
	03-Oct	23	8.10	8.20	8.06

App4-Table 6f: Thermocline Depth and Dissolved Oxygen in B-Zone Pit, 1995-1999.

Year	Date	Thermocline	Dissolved Oxygen (mg/L)		
		(m)	0 or 1 m	5 m	20 m
1995	12-Apr	No	13.59	12.84	9.96
	14-Jun	3	11.49	16.39	14.87
	17-Aug	10	10.79	9.84	10.24
	14-Oct	20	11.86	11.80	9.90
1996	09-May	No	11.02	10.39	9.78
	26-Aug	9	10.20	10.45	10.72
	28-Oct	No	13.21	13.20	13.20
1997	Mar-Apr		NOT AVAILABLE		
	29-Jun	6	9.19	10.24	9.83
	12-Aug	8	8.79	9.04	9.11
	06-Oct	23	10.54	10.99	12.02
1998	18-Apr	No	9.61	9.68	8.10
	01-Jun	No	8.80	8.55	8.11
	02-Sep	10	9.26	9.12	9.24
1999	17-Apr	No	12.70	12.39	10.00
	18-Jun	No	12.04	12.60	9.91
	10-Aug	8	9.50	9.14	9.81
	03-Oct	23	10.06	10.27	9.94

App4-Table 6g: Thermocline Depth and Eh in B-Zone Pit,

1995-1999.

Year	Date	Thermocline	Eh (mV)		
		(m)	0 or 1 m	5 m	20 m
1995	12-Apr	No	400	397	403
	14-Jun	3	281	307	337
	17-Aug	10	349	374	408
	14-Oct	20	387	384	393
1996	09-May	No	533	545	548
	26-Aug	9	358	350	376
	28-Oct	No	327	328	326
1997	Mar-Apr		NOT AVAILABLE		
	29-Jun	6	102	104	131
	12-Aug	8	108	109	141
	06-Oct	23	74	79	88
1998	18-Apr	No	84	89	103
	01-Jun	No	181	177	181
	02-Sep	10	152	145	155
1999	17-Apr	No	80	89	112
	18-Jun	No			
	10-Aug	8	128	129	152
	03-Oct	23	398	384	387

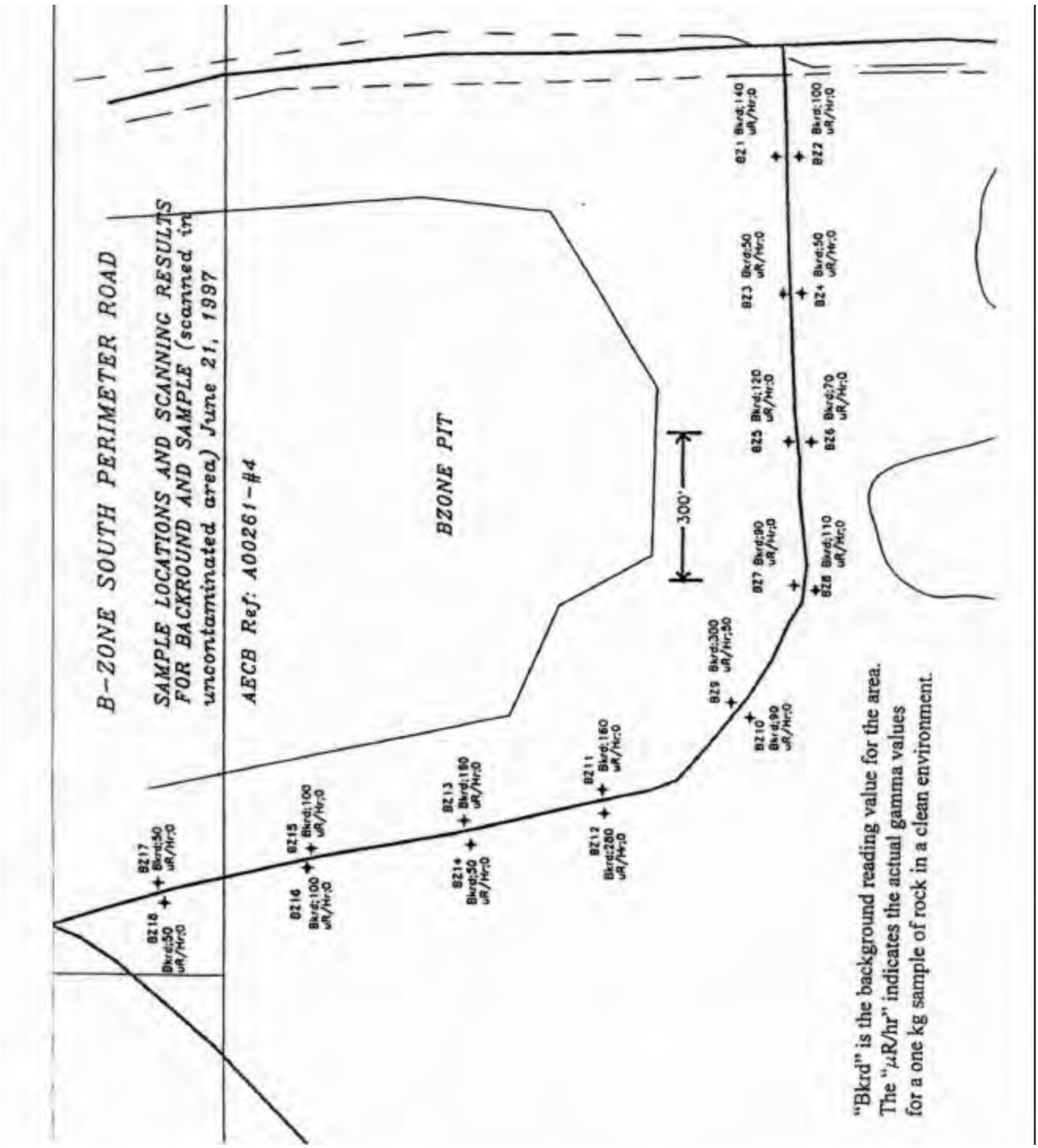
App4-Table 7: Sedimentation rates in the B-Zone Area

Station	Depth m	Sample total DW (g)	Sedimentation rate (g/m^2/day)
B-Zone Pit	**From 11-Jun-93 to 13-Aug-93, 63 days**		
6.72	2	14.71	23.79
	12	16.64	26.91
	22	14.24	23.02
	32	17.74	28.68
	From 26-Jun-94 to 8-Sept-94, 74 days		
	2	4.49	6.20
	12	10.58	14.60
	22	12.61	17.35
	32	8.41	11.58
	From 26-Jun-95 to 10-Aug-95, 45 days		
	2	6.37	14.42
	12	3.83	8.66
	22	5.30	12.00
	32	4.49	10.17
	From 10-Aug-95 to 16-Sept-95, 37 days		
	2	6.12	21.00
	12	4.69	12.91
	22	5.52	15.20
	32	5.78	15.90
	From 5-Jul-96 to 30-Aug-96, 56 days		
	2	0.90	1.64
	12	2.91	5.29
	22	1.94	3.52
	32	no sample	
	From 17-Jun-97 to 26-Aug-97, 70 days		
	2	0.80	1.20
	12	1.65	2.40
	22	1.65	2.40
	32	no sample	
	From 25-Jun-98 to 1-Sept-98, 68 days		
	2	1.25	1.87
	12	1.75	2.62
	22	1.90	2.84
	32	1.70	2.54
B-Zone Pit	**From 31-Aug-98 to 29-Sept-98, 29 days**		
6.73	4	0.45	1.6
Collins Bay	**From 31-Aug-98 to 29-Sept-98, 29 days**		
6.12	9	1.6	5.6
Ivison Bay	**From 31-Aug-98 to 29-Sept-98, 29 days**		
6.10	9	0.5	1.8

App4-table 8: Total Biomass of Phytoplankton Grouped by Phyla in B-Zone Flooded Pit (1995-98)

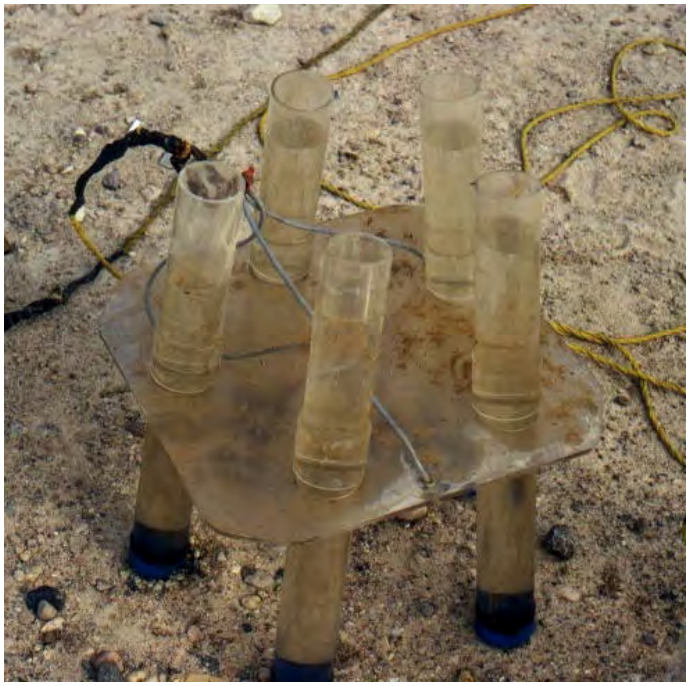
unit: (mg/l)

Phylum	1996		1997	1998
	Apr	Aug	Aug	Sep
0 m				
Cyanobacteria	0	0	0.027	0.0043
Chlorophyta	0.3707	0.90	0.045	0.030
Euglenophyta	0	0	0	0
Chrysophyta	0	0.0012	0.020	0.023
Cryptophyta	0.0014	0.0032	0.0014	0.0060
Pyrrophyta	0	0.013	0.019	0.016
Diatoms	0	0.0048	0.0043	0.0108
Rhodophyta	0	0	0	0
Total	0.37	0.92	0.12	0.090
2 m				
Cyanobacteria	0	0	0.028	0.0069
Chlorophyta	0.51	1.01	0.052	0.019
Euglenophyta	0	0	0	0
Chrysophyta	0	0.0013	0.022	0.024
Cryptophyta	0.00033	0.00060	0.0086	0.021
Pyrrophyta	0	0.018	0.059	0.016
Diatoms	0.00078	0.00024	0.0031	0.0023
Rhodophyta	0	0	0	0
Total	0.51	1.03	0.17	0.089
12 m				
Cyanobacteria	0	0	0.025	0.0058
Chlorophyta	1.04	0.34	0.014	0.067
Euglenophyta	0	0	0	0.00074
Chrysophyta	0	0.0024	0.010	0.0050
Cryptophyta	0.00083	0	0.00076	0.14
Pyrrophyta	0	0.0055	0.0029	0.012
Diatoms	0.00017	0.00059	0.0024	0.0017
Rhodophyta	0	0.00	0	0
Total	1.04	0.349	0.055	0.23
22 m				
Cyanobacteria	not sampled	0	0.0059	0.0047
Chlorophyta		0.48	0.017	0.032
Euglenophyta		0	0	0
Chrysophyta		0.0011	0.0050	0.0036
Cryptophyta		0	0.0039	0.0071
Pyrrophyta		0.0082	0.0020	0.0014
Diatoms		0.00066	0.0026	0.022
Rhodophyta		0	0	0
Total		0.491	0.036	0.071
32 m				
Cyanobacteria	0	0.00	0.002	0.0024
Chlorophyta	2.24	0.83	0.012	0.018
Euglenophyta	0	0	0	0
Chrysophyta	0	0.0011	0.0029	0.0041
Cryptophyta	0.0021	0.00035	0	0.0016
Pyrrophyta	0	0.012	0.0031	0
Diatoms	0	0	0.0028	0.0047
Rhodophyta	0	0	0	0
Total	2.24	0.838	0.023	0.031
42 m				
Cyanobacteria	0	not sampled	0.0055	0.0027
Chlorophyta	2.05		0.061	0.012
Euglenophyta	0		0	0
Chrysophyta	0		0.0027	0.00024
Cryptophyta	0.00042		0	0.00047
Pyrrophyta	0		0.0049	0
Diatoms	0		0.0066	0.0042
Rhodophyta	0		0	0
Total	2.05		0.081	0.020

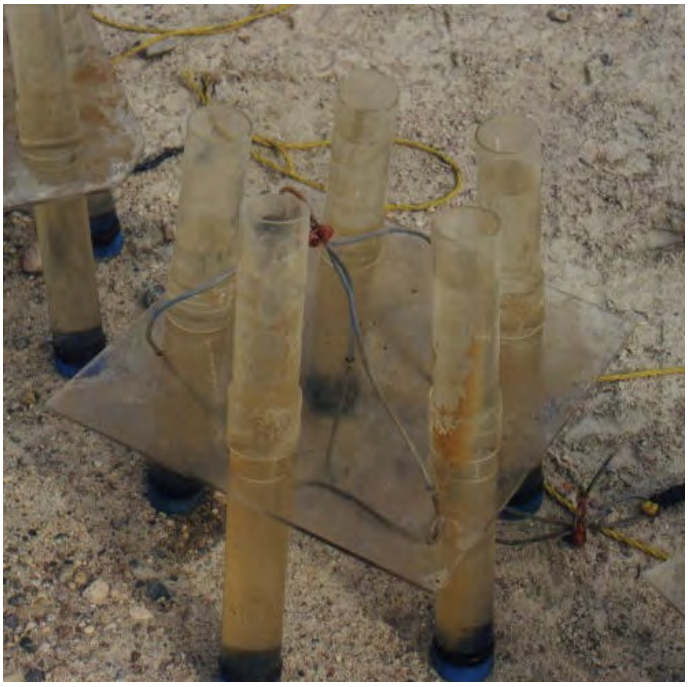


Map of B-Zone Pit southwest perimeter road bed waste rock sampling locations (M.Baldero, Cameco, June, 1997)

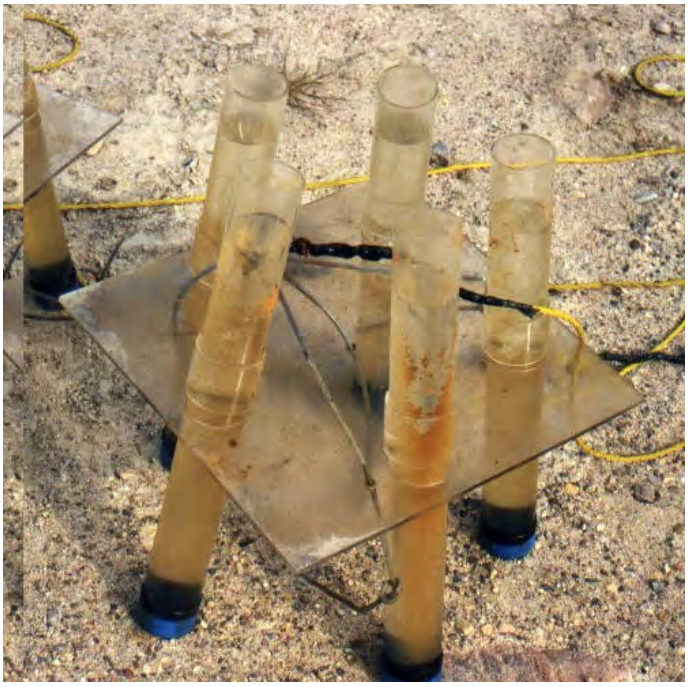
App4-Plate 1: B-Zone sedimentation trap collected at station 6.72 from 2m depth.



App4-Plate 2: B-Zone sedimentation trap collected at station 6.72 from 12m depth.



App4-Plate 3: B-Zone sedimentation trap collected at station 6.72 from 22m depth.



App4-Plate 4: B-Zone sedimentation trap collected at station 6.72 from 32m depth.

Sedimentation Trap Installation and Sampling

Sedimentation traps were installed in D-Lagoon and the East and West pons of B-Lagoon. The design of the traps follows specifications outlined by Bloesch and Burns, 1980. These traps are each comprised of five polycarbonate vertical tubes capped at the bottom. These traps are placed at the pond bottom in order to capture downward settling particles. Upon recovery, the collected sediment is sampled and the sediment's wet weight and volume are measured. The material is dried at 60 ^{o}C for 24 hours before weighing. Sedimentation rates are expressed as grams dry weight per square meter per day ($g.m^{-2}.d^{-1}$).

Bloesch, J., urns, 1980. A critical review of sedimentation trap technique. Schweiz. Z. Hydrol. 42: 15-55.

Appendix 5

External Ni Sources

TABLE OF CONTENTS

B-Zone Pond Perimeter
Investigation of Ni Contamination

CAMECO

2000

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

LIST OF APPENDIXES

B-ZONE POND PERIMETER - INVESTIGATION OF NI CONTAMINATION

1 INTRODUCTION

This document reports on an investigation of suspected nickel loading to the B-zone pond due to mineralized soils contained in the perimeter areas of the B-zone pond.

The issue of contamination in the road along the south and west sides of the B-zone pond was first addressed by Mr. Peter Courtney of the AECB in 1997. At that time the issue was raised in the context of above-background gamma fields.

In June of 1997, as a follow-up to Mr. Courtney's comments, Cameco collected rock samples from the roadbed for measurement of the gamma field. A report was issued to the regulatory agencies with respect to the radiation question (Letter from L. Marcinkoski to P. Courtney, July 31, 1997). Subsequent to that, the soil samples were analyzed for As, Ni, S and U. The results of these analyses showed As and Ni levels somewhat higher than typically found in the B-zone waste rock pile. Appendix 1 contains a tabular listing of analytical data and a sketch showing the sampling locations. These data indicate that the potential for contaminant loadings originating from the road cannot be ruled out.

In June of 1999, personnel from Boojum Technologies noted a "blue crusting" along the perimeter road. Surface samples of this evaporite were collected during a B-Zone environmental sampling campaign for analysis of metals. Analysis of the blue crust material revealed a high concentration of soluble nickel. In addition, Boojum collected samples of runoff water from this area, during a rainfall event; this runoff water showed elevated levels of nickel. Very preliminary, order-of-magnitude mass loading calculations by Boojum suggest that up to 10% of the total nickel load in the pond may be replenished each year by runoff from the road. (This estimate assumed, however, that very limited sedimentation and bottom sediment data in the B-zone pit accurately reflected the natural removal rate of nickel from the water column.)

In view of the on-going elevated nickel concentration in the B-zone Pond and the above information regarding the B-zone perimeter road, Cameco performed a follow-up investigation of potential contamination from mineralized material located around the pond perimeter.

2 PROJECT OBJECTIVES AND METHODOLOGY

The objectives of this project were to:

- Investigate possible sources of nickel loading around the B-zone Pond;
- Determine whether these sources represent significant loadings to the B-zone Pond; and
- Provide recommendations for remediation, if required.

3 FIELD INVESTIGATION

3.1 *Field Reconnaissance*

A field reconnaissance (on foot) of the B-zone pond perimeter area was performed by Patrick Landine of Cameco on June 6, 2000. The reconnaissance began at the northeast corner of the pond, (Area A, Figure 1) and proceeded in a clockwise fashion from there, returning to the starting point. Please refer to Figure 1 for the location of Areas (A, B, C etc) discussed in the following paragraphs.

The shoreline along the east side in the northern half (area A) is relatively flat. Water enters the pond by diffuse seepage (soft ground), and as a stream from an old culvert under the haul road and from other, more noticeable, seeps. Photograph 1 shows a stream channel originating at the above noted culvert under the main haul road. Soils appear to be native to the area.

Further south along the east side of the pond (Area B, C, D and E), erosion and slumpage of bank material into the pond was observed in several locations. Photograph 2 shows an eroded area (Area B) of shoreline in material with a high fines content. It was not possible to determine whether the soil material was native to the area or spoil material placed during mining of the pit.

In the south half of the east side, some changes in slope geometry are evident in the form of flow slides (Area C, Photograph 3) and toppling blocks (Area D, Photograph 4 and 5). These appear to be caused by moderate shoreline erosion due to wave action. The material falling into the pond appeared to be a mixture of till and waste rock in Area D (Figure 1), natural soil and peat materials in other areas (C and E). Photograph 6 shows a close view of the waste rock/till material, which is toppling into the pond in Area D.

Water is entering the pond from a couple of seeps along the side of the boat ramp at the south end. Numerous groundwater seeps were found along the east, south and west sides of the pond.

In Area F, (from the boat ramp to the southwest corner), mass-wasting is occurring in high banks of peat on the shore. Seepages in this area may be made up of bog water and runoff/infiltration from the perimeter road above.

In the southwest corner (Area G), slope wash erosion from the Perimeter road and the shoulder berm between the road and the pond is being carried directly into the pond, as shown in Photographs 7 and 8. The road in this area was showing a very light blue-green efflorescence.

Photograph 9 shows minor mass-wasting in natural soil/peat along the west side of the pond in Area H (Figure 1). This photograph is typical of similar features in Area E and F as well.

The southwest perimeter road was found to have visible signs of nickel mineralization, including blue colouration and blue crusting. The road was also found to be subject to erosion, with a portion of the sediment arriving in the pond while the remainder appeared to be trapped in the peat bog between the road and the pond. Large alluvial fans extend from the road shoulder berm into the bog area (Area I), as shown in Photograph 10.

Along the west side, runoff from the perimeter road flows into the peat and thence to the pond. (Runoff also flows from the road to the outside bog.) The road along the west side was dark blue-

green in a couple of areas (Photograph 11), suggesting high arsenic (As) and nickel (Ni) content. The area of generalized blue-green coloration was confined to Area K, as indicated on Figure 1.

No concerns were found north of the junction of the southwest perimeter road and the B-zone dyke road (Area J, Figure 1). No concerns with potential nickel sources were found anywhere along the B-zone dyke structure.

3.2 *Soil and Water Sampling*

Soil and water samples were collected at the locations indicated on Figure 2, beginning in August 2000. Table 1, provides a list of the soil/rock samples including comments on sample matrix, depth and colour. Table 2 provides a listing of water samples.

Soil and water samples were analyzed at the SRC laboratory in Saskatoon.

4 DATA ANALYSIS AND DISCUSSION

4.1 *Chemical Analysis Results*

Soil sample analysis results are listed in Tables 3 to 6. Water sample analysis results are listed in Table 7. In these tables, data lines for As and Ni have been emphasized, for ease of reading, through the use of bold lettering.

4.1.1 *East Side of Pond*

Table 3 lists results for soil/rock samples collected along the east side of the B-zone Pond. Note that samples from locations BZHR5 and 6 show moderate levels of As and Ni, while samples from locations BZHR7 to 9 show very low levels of these metals. In the field reconnaissance, it was observed that materials around locations BZHR5 and 6 (Area D) appeared to consist of a mixture of waste rock and till. The measured As and Ni concentrations, as well as other elements, for these materials are similar to those reported in "Collins Bay B-zone Decommissioning Year 1", Cameco (1993) (Table 5 - Appendix 3A) for quartzite and sandstone waste rock material. A copy of Table 5 from Cameco (1993) is included in Appendix 1 for easy reference.

Further north near locations BZHR8 and 9 (Areas B and A respectively) the materials appeared to be native to the area. The elemental composition of these materials is similar to that reported for till in Cameco (1993).

As noted in the field reconnaissance, material represented by samples from BZHR5 and 6 is entering the B-zone Pond in significant quantities due to slope erosion along the shoreline. The potential quantity of Ni entering the pond has been estimated based on an assumed rate of shoreline erosion and the measured Ni concentration in samples from BZHR5 and 6. Based on field observations, it may be assumed that up to 1 m^3 of material per meter of shoreline over a distance of 220 m is falling into the pond annually. The density of waste rock is typically about 1.8 t/m^3, which results in a total mass load of about 400 t/yr. Given an average Ni concentration of 500 ③g/g, the total amount of Ni

added would be about 200 kg/yr. If 10% of this Ni were dissolved, it would raise the concentration of Ni in the B-zone Pond by about 0.004 mg/L (pond volume of 5.3×10^6 m^3). (Shake flask tests previously conducted on B-zone waste rock (Cameco 1993 and Boojum 1997), showed a maximum of about 10% dissolution for nickel.) This incremental concentration is small when compared to existing Ni concentrations of about 0.25 mg/L in the pond, although, it may be a contributing factor in maintaining the current Ni concentration.

Two water samples (Table 7) were collected along the east side of the B-zone Pond. The sample taken from a standing water pool at BZHR3 shows elevated levels of Ni and As. The source of this water would be runoff from the shoulder of the Haul Road and seepage from the bog on the opposite side of the road. No estimate of the mass load contribution from this source is possible.

The water sample taken from BZHR4 shows lower concentrations for Ni and As, but still above the applicable Saskatchewan Surface Water Quality Objective to protect aquatic life (SSWQO). The estimated flow rate at this location was 0.5 L/min. If this flow rate was maintained for the entire year (conservative) at a Ni concentration of 0.12 mg/L, the annual increase in Ni concentration of the pond would be about 6×10^{-6} mg/L, an insignificant amount.

4.1.2 *South Side of Pond*

Table 4 lists the results of chemical analyses for soil/rock samples collected along the south side of the B-zone Pond. Samples taken at locations SWPR9 and 23 were logged as till material. The measured As and Ni concentrations for these materials are similar to those reported in Cameco (1993) and Boojum (1997) for till material.

Soils at sample locations SWPR20, 21 and 22 were field logged as sandstone. SWPR14 was not field logged, but the chemical analysis results suggest it is very similar to the remaining samples in this group. Comparison of metal concentrations for these samples with those listed in Cameco (1993) and Boojum (1997) for sandstone show similar values. The results of shake flask tests reported in Cameco (1993) and Boojum (1997) indicate low water-extractable metals for sandstone.

Three water samples, SWPR12, 13 and 15 (Table 7), were collected along the south side of the B-zone Pond. All of these samples display concentrations greater than the SSWQO for As, Ni and ^{226}Ra. There are two potential reasons for this; one is that pockets of rock with higher leach potential may exist in the area. The second is that rainfall/runoff water (initially at low metal concentrations) collected in these small ponds is concentrated by evaporation over a period of days or weeks.

4.1.3 *West Side of Pond*

Table 5 lists the results of chemical analyses for soil/rock samples collected along the west side of the B-zone Pond. Two samples in this group, SWPR5 and 16, show low levels of As and Ni. SWPR16 was collected near the shore of the B-zone pond to the north of the perimeter road (Figure 2) in natural silty material. There is no concern with this material. SWPR5 was collected at the toe of the perimeter roadbed in alluvial sand that had been washed from the road. The material at this location does not pose a concern in terms of Ni contamination.

All other samples in this group were collected in areas of obvious blue surface coloration and nuggets of blue coloured rock. The concentrations of As and Ni range from about 1,000 ③g/g to

16,000 ③g/g in this area, compared to maximums of 676 ③g/g (As) and 1,481 ③g/g (Ni) reported in Cameco (1993) for quartzite/sandstone and graphitic gneiss, (Table 5 Appendix 1 of this report).

Four water samples (Table 7) were collected along the west and southwest side of the pond. Samples collected at SWPR7 and 8 show relatively low levels of As and Ni, suggesting that seepage in this area is not contributing significantly to the Ni load in the pond. The sample collected at SWPR11 showed high concentrations of As and Ni. This sample was collected from a pond located on the "outside" of the perimeter road close to the portion of the road with the highest As/Ni concentrations. On the opposite side of the road (toward the B-zone pond) at SWPR5, the Ni concentration was similar to that at SWPR11, while the As concentration was much lower. This may indicate that As is being adsorbed in the sand materials, but the Ni is passing through with little attenuation.

In order to determine the depth and extent of As/Ni mineralization along this section of the perimeter road, four test pits were excavated at SWPR24, 25, 26 and 27. Test pit logs are included in Appendix 2. Analysis of samples (Table 6) from the test pits showed that in the area of SWPR24, 25 and 26, the As/Ni contaminated waste rock extended from the surface to a depth of about 1.3 m. Test pit SWPR26 was excavated at the boundary of the mineralized material, with one half of the pit in each material. Test pit SWPR27 was excavated further south in material that did not appear to be contaminated (blue). Samples of the upper mineralized material from each pit were composited under the name SWPR24A prior to shipment to the laboratory. Samples of the apparently non-mineralized material from SWPR24, 25 and 26 were composited together under the name SWPR24B prior to shipment to the laboratory. The analytical results confirm the visual observation of mineralization; SWPR24A contains significant levels of As and Ni, while SWPR24B and SWPR27 have low to very low levels of As and Ni.

The volume of significantly mineralized material may be calculated on the basis of field observations and analytical results. The portion of the road containing mineralized material is about 14 m wide by 250 m long and 1.3 m thick, with a total volume of 4,550 m^3.

4.2 *Summary of Investigation Findings*

The investigation has shown that mineralized soil/rock exists in the B-zone perimeter road along the west side of the pond. This material appears to be a source of metal loading (primarily Ni and As) to the surrounding bog on the outside of the road and may be a source of metal loading to the B-zone Pond. The magnitude of the source term can not be estimated based on the available data. A program to collect data for the purpose of estimating the flux would be complicated and time-consuming. Removal of the problematic material and monitoring the results would be less costly than studying the issue.

The road materials on the south side of the pond do not appear to be highly contaminated; however, water samples collected in the area show some elevated concentrations. These elevated concentrations may be due to pockets of mineralized rock or evaporative concentration of runoff water.

The banks of the B-zone Pond are somewhat unstable along several sections of the shore. This is not a concern in areas where the shoreline consists of natural material. However, in one stretch along the east side of the pond (Area D, Figure 1), mass-wasting is occurring in material that appears to be

quartzite and sandstone waste rock. Although it will be agreed that the material is going back from whence it came, it has oxidized, and the quantity of nickel entering the pond due to mass-wasting in this area may be a factor (minor) in pond water quality.

A small amount of contaminated water is entering the northeast part of the pond via a stream channel originating from a plugged culvert beneath the Haul Road. The quantity of contaminates is insignificant and thus does not merit further attention.

5 RECOMMENDATIONS

5.1 *West Side Contaminated Roadbed*

The significantly mineralized portion of the Southwest Perimeter Road should be removed. This does not include the shoulder berm portion of the road, which appears to consist of till and sandstone. The portion to be removed would extend from the approximate location of SWPR10 to SWPR27 (Figure 2). The estimated volume of material is 4,550 m^3. The spoil material would be placed on the B-zone Waste Rock Stockpile. This action is not expected to cause any immediate improvements to the B-zone pond water quality, as there is no conclusive proof that contaminants from the road are reaching the B-zone pond. However, the action would be justified on the basis that mineralized waste rock, which the material in question is, should, if found in significant quantities, be stored on the waste rock stockpile.

Excavation control should be performed by an experienced field technician using visual techniques (soil/rock colour, type). Upon completion of the excavation, confirmatory investigations, including test pits through the full thickness of the roadbed should be performed to show that the mineralized material has been removed. After completion of all removal activities, the road would be graded to ensure that no small surface water ponds are formed.

5.2 *East Side Shoreline Stabilization*

Shoreline stabilization is required on the east bank of the pond in the area delineated as "D" in Figure 1. Waste rock material in this area should be excavated and moved to the B-zone Waste Rock Stockpile. Visual techniques combined with selective testing should be used to select material for removal to the B-zone pile. After completion of excavation activities the shoreline should be sloped toward the pond until a stable slope of about 3H:1V is obtained. This may be done by removing material or by pushing clean shoreline materials into the pond. The total volume of material to be removed or pushed would be about 3,400 m^3. After final sloping, the area should be protected with vegetation by hydroseeding.

5.3 *Small Ponds and Pockets of Mineralization*

The surface water body located at SWPR11 should be filled with clean till material to prevent the re-establishment of any water body at this location.

Any visually identifiable surficial pockets of mineralized material located along any section of the road, shoulder berm or east bank of the pond should be removed. Spoil material should be placed on the B-zone Waste Rock Stockpile.

The road and bank surfaces along the southwest, south and southeast perimeter areas of the B-zone pond should be graded/filled to prevent the formation of small stagnant ponds where evaporative concentration of contaminants could occur.

6 REFERENCES

Cameco, 1993. *Collins Bay B-zone Decommissioning Year 1 Proposed Target Levels*. July 1993.

Boojum, 1997. *Decommissioning of the B-zone Waste Rock Pile 1996 Final Report.* Boojum Technologies, March 12, 1997.

Table 1 List of soil/rock samples collected in perimeter areas of B-zone Pond during August and September of 2000.

Location	Sample Number	Sample Description
BZHR5	BZHR5-s 2000.09.17	Composite, waste rock with clay and sand, minor blue coloration.
BZHR6	BZHR6-s 2000.09.17	Composite, waste rock with clay and sand, located near a boulder with blue coloration, but no obvious coloration at the sample site.
BZHR7	BZHR7-s 2000.09.17	Composite, sandy till with some boulders, no visible blue coloration.
BZHR8	BZHR8-s 2000.09.17	Composite, medium sandy till, undisturbed (ie. Not fill)
BZHR9	BZHR9-s 2000.09.17	Composite, silty till, undisturbed (ie. Not fill)
SWPR1	SWPR1-s 2000.08.18	Taken from area of obvious blue discoloration. Blue nuggets visible. RLO Lab analysis of blue nuggets only indicated about 20% Ni content. This sample is bulk material. (See Photograph 12)
SWPR10	SWPR10-s 2000.08.24	Fine grained alluvial fan material along shoulder of road. Some blue coloration of surface.
SWPR14	SWPR14-s 2000.08.24	Bulk sample of roadbed material. No obvious blue coloration.
SWPR16	SWPR16-s 2000.09.05	Composite, silt some sand, saturated, spongy.
SWPR17	SWPR17-s 2000.09.05	Composite of waste rock with blue coloration.
SWPR18	SWPR18-s 2000.09.05	Composite of waste rock with blue coloration.
SWPR19	SWPR19-s 2000.09.05	Composite of waste rock with blue coloration.
SWPR20	SWPR20-s 2000.09.07	Composite sandstone with some graphite, no blue coloration,
SWPR21	SWPR21-s 2000.09.07	Composite, Sandstone, no blue coloration.
SWPR22	SWPR22-s 2000.09.07	Composite, Sandstone, no blue coloration.
SWPR23	SWPR23-s 2000.09.16	Composite, sand with some gravel.
SWPR24	SWPR24A-s 2000.09.16	Test pit sample in area of obvious blue coloration. This sample composited with SWPR25A and SWPR26A for analysis, results reported under SWPR24A. Waste rock.
	SWPR24B-s 2000.09.16	Test Pit sample below surface layer with blue colour at a depth of 1.7 m. This sample composited with SWPR25B and SWPR26B for analysis, results reported under SWPR24B. Sandy Till
SWPR25	SWPR25A-s 2000.09.16	Test pit sample in area of obvious blue coloration. This sample composited with SWPR24A and SWPR26A for analysis, results reported under SWPR24A. Waste rock.
	SWPR25B-s 2000.09.16	Test Pit sample below surface layer with blue colour at a depth of 1.7 m. This sample composited with SWPR24B and SWPR26B for analysis, results reported under SWPR24B. Sandy Till
SWPR26	SWPR26A-s 2000.09.16	Test pit sample in area of obvious blue coloration. This sample composited with SWPR25A and SWPR24A for analysis, results reported under SWPR24A. Waste rock.
	SWPR26B-s 2000.09.16	Test Pit sample beside surface layer with blue colour at a depth of 0.7 m. This sample composited with SWPR25B and SWPR24B for analysis, results reported under SWPR24B. Sandy Till
SWPR27	SWPR27-s 2000.09.16	Test pit sample at a depth of 1.2 m from an area with no obvious coloration or blue nuggets. Sandy till.
SWPR5	SWPR5-s 2000.08.19	Sample of alluvial sand from along shoulder of road.,
SWPR9	SWPR9-s 2000.08.21	Composite of silty till material. Technician, was not sure if undisturbed material.

Table 2: List of water samples collected in perimeter area of B-zone pond during August and September of 2000.

Location	Sample Number	Sample Description
BZHR3	BZHR3-w 2000.08.23	Sample dipped from standing surface water. Standing pool of runoff water located between the main haul road and the B-zone Pond.
BZHR4	BZHR4-w 2000.08.23	Sample collected by building a small weir across the stream. Flow was measured to be 8 mL/s.
SWPR11	SWPR11-w 2000.08.23	Sample dipped from standing surface water.
SWPR12	SWPR12-w 2000.08.23	Sample dipped from standing surface water.
SWPR13	SWPR13-w 2000.08.24	Sample dipped from standing surface water.
SWPR15	SWPR15-w 2000.08.24	Sample dipped from standing surface water.
SWPR5	SWPR5-w 2000.08.19	Water sample squeezed from peat excavated from 40 to 65 cm depth.
SWPR7	SWPR7-w 2000.08.19	Sample collected in a cistern installed at seepage point.
SWPR8	SWPR8-w 2000.08.19	Sample collected in a cistern installed at seepage point.

Table 3 Soil Chemistry for Samples collected along the **east** side of the B-zone Pond.

Analyte	Units	Sample Number				
		BZHR5-s 2000.09.17	BZHR6-s 2000.09.17	BZHR7-s 2000.09.17	BZHR8-s 2000.09.17	BZHR9-s 2000.09.17
Ag	µg/g	0.5	0.5	0.5	0.5	0.5
Al	µg/g	11300	24600	7600	8600	4700
As	µg/g	**480**	**520**	**10**	**1.8**	**2.1**
Ba	µg/g	26	39	33	40	25
Be	µg/g	0.9	1.4	0.6	0.7	0.5
B	µg/g	1	18	3	5	1
Ca	µg/g	860	670	2500	1100	1700
Cd	µg/g	0.5	0.5	0.5	0.5	0.5
Co	µg/g	3.3	4.4	2.4	3.3	2
Cr	µg/g	25	36	31	77	25
Cu	µg/g	3.8	4	4.5	5.3	5.1
Fe	µg/g	2500	3200	8500	10400	7400
K	µg/g	2700	5900	1700	2900	1200
Mg	µg/g	2600	5600	4800	3500	1700
Mn	µg/g	37	40	110	150	91
Mo	µg/g	9.8	8.9	0.5	0.5	0.5
Na	µg/g	70	120	210	220	220
Ni	µg/g	**530**	**490**	**20**	**9.4**	**6.4**
Pb	µg/g	9	10	4	4	3
P	µg/g	440	330	300	210	320
Sr	µg/g	200	200	24	8.8	16
Ti	µg/g	7.3	12	390	470	420
V	µg/g	29	48	17	17	14
Zn	µg/g	7.9	12	14	20	12
Zr	µg/g	2.6	3.9	8.9	6.8	7.9

Table 4 Soil Chemistry for samples collected along the **south** side of the B-zone Pond.

Analyte	Units	Sample Number					
		SWPR9-s 2000.08.21	SWPR14-s 2000.08.24	SWPR20-s 2000.09.07	SWPR21-s 2000.09.07	SWPR22-s 2000.09.07	SWPR23-s 2000.09.16
Ag	µg/g	0.5	0.5	0.5	0.5	0.5	0.5
Al	µg/g	14600	11500	16700	6500	9100	10800
As	µg/g	**66**	**310**	**180**	**110**	**220**	**79**
Ba	µg/g	31	33	48	17	27	29
Be	µg/g	0.8	0.7	1.1	0.5	0.6	0.7
B	µg/g	68	12	7	4	19	2
Ca	µg/g	590	550	580	290	970	1100
Cd	µg/g	0.5	0.5	0.5	0.5	0.5	0.5
Co	µg/g	2.3	11	3	2.4	3.2	2.4
Cr	µg/g	27	22	58	25	26	36
Cu	µg/g	7.5	58	5	8.3	15	5.7
Fe	µg/g	6200	5800	4200	3500	6900	5100
K	µg/g	4000	3100	4800	1800	2300	2300
Mg	µg/g	3000	1900	4200	1400	2000	3100
Mn	µg/g	66	130	70	35	72	45
Mo	µg/g	2.3	7	3.8	6.7	12	3.7
Na	µg/g	220	110	110	50	120	110
Ni	µg/g	**57**	**130**	**200**	**67**	**120**	**64**
Pb	µg/g	16	32	11	15	25	13
P	µg/g	200	160	240	120	240	420
Sr	µg/g	99	87	92	61	55	53
Ti	µg/g	71	46	64	22	200	110
U	µg/g			91.8			
V	µg/g	71	41	52	25	36	26
Zn	µg/g	9.6	11	11	10	11	9.6
Zr	µg/g	14	13	7.2	5.8	13	7

Table 5 Soil Chemistry for Samples collected along the **west** side of the B-zone Pond.

Analyte	Units	Sample Number						
		SWPR1-s 2000.08.18	SWPR5-s 2000.08.19	SWPR10-s 2000.08.24	SWPR16-s 2000.09.05	SWPR17-s 2000.09.05	SWPR18-s 2000.09.05	SWPR19-s 2000.09.05
Ag	µg/g	1.3	0.5	4.8	0.5	0.5	1.1	0.7
Al	µg/g	58900	8000	38900	7300	22900	46400	39600
As	µg/g	**6900**	**160**	**2800**	**3**	**930**	**4700**	**15800**
Ba	µg/g	110	43	84	36	55	120	63
Be	µg/g	3.2	0.5	4	0.5	1.3	2.9	2.4
B	µg/g	130	13	180	5	13	84	91
Ca	µg/g	480	1900	1700	3000	380	400	400
Cd	µg/g	0.5	0.5	0.8	0.5	0.5	0.5	0.5
Co	µg/g	16	5.5	360	2.8	3.3	14	16
Cr	µg/g	35	25	33	22	29	37	30
Cu	µg/g	6.5	18	670	6.2	3.3	5.8	10
Fe	µg/g	2000	9000	27800	10900	1800	2000	4200
K	µg/g	21000	2500	11900	1500	6400	14800	13900
Mg	µg/g	8600	2400	4000	2400	3600	7200	3600
Mn	µg/g	51	110	590	150	34	43	44
Mo	µg/g	170	4.4	80	0.5	51	130	300
Na	µg/g	320	210	400	280	120	210	180
Ni	µg/g	**6900**	**140**	**5900**	**8.5**	**1000**	**4900**	**16000**
Pb	µg/g	64	17	370	3	18	92	190
P	µg/g	330	350	400	480	250	330	310
Sr	µg/g	290	27	130	25	250	330	390
Ti	µg/g	11	510	280	790	2.5	15	9.9
U	µg/g					227		
V	µg/g	650	30	380	19	90	310	340
Zn	µg/g	17	18	100	18	7	15	9.4
Zr	µg/g	12	18	110	12	3.9	7.2	13

Table 6: Soil Chemistry for Samples collected from **test pits** along the **west** side of the B-zone Pond.

Analyte	Units	Sample Number		
		SWPR24A-s 2000.09.16	SWPR24B-s 2000.09.16	SWPR27-s 2000.09.16
Ag	µg/g	0.5	0.5	0.5
Al	µg/g	26800	7000	8500
As	µg/g	**4000**	**230**	**17**
Ba	µg/g	47	37	33
Be	µg/g	1.4	0.5	0.5
B	µg/g	1	3	9
Ca	µg/g	580	2100	1300
Cd	µg/g	0.5	0.5	0.5
Co	µg/g	9	3.4	2.2
Cr	µg/g	29	20	36
Cu	µg/g	4.8	9.4	4.4
Fe	µg/g	2200	9000	6200
K	µg/g	6300	1400	2000
Mg	µg/g	5000	2600	2000
Mn	µg/g	42	120	90
Mo	µg/g	81	2.7	2.2
Na	µg/g	130	230	200
Ni	µg/g	**4000**	**110**	**19**
Pb	µg/g	44	11	7
P	µg/g	300	370	280
Sr	µg/g	230	24	83
Ti	µg/g	16	520	300
V	µg/g	150	22	30
Zn	µg/g	7.2	16	11
Zr	µg/g	5	9.2	13

Table 7 Water chemistry for samples collected around the perimeter of the B-zone Pond.

	Sample Number									
Analyte, mg/L	BZHR3-w 2000.08.23 [1]	BZHR4-w 2000.08.23 [1]	SWPR11-w 2000.08.23	SWPR12-w 2000.08.23	SWPR13-w 2000.08.24	SWPR15-w 2000.08.24	SWPR5-w 2000.08.19 [1,2]	SWPR7-w 2000.08.19 [1,2]	SWPR8-w 2000.08.19 [1,2]	SSWQO [3]
Ag			0.001	0.001	0.001	0.001				
Al			0.47	0.13	0.43	0.11				
As	**6.1**	**0.22**	**36**	**0.13**	**2.5**	**0.74**	**0.44**	0.049	**0.061**	0.05
Ba			0.027	0.013	0.023	0.016				1
Be			0.001	0.001	0.001	0.001				
B			0.034	0.02	0.043	0.032				
Ca			25	13	25	9.2				
Cd			0.001	0.001	0.001	0.001				
Co			0.008	0.14	0.004	0.003				
Cr			0.002	0.002	0.001	0.001				
Cu			**0.012**	**0.32**	**0.012**	0.002				0.01
Fe			0.76	0.46	0.56	0.23				1
K			8.1	3.3	5.8	4.2				
Mg			11	5.2	9.6	3.9				
Mn			0.65	2.8	0.41	0.1				
Mo			1.2	0.014	0.16	0.08				
Na			3.8	2.7	3.2	2.7				
Ni	**3.9**	**0.12**	**3.9**	**1.5**	**0.62**	**0.83**	**3.2**	**0.16**	**0.15**	0.025
Pb			0.005	0.002	0.011	0.002				0.02
pH	6.63	6.18	6.3	6.58	7.17			6.49	6.62	
Ra226			**0.6**	**0.6**						0.11
Si			5.1	4.7	4.2	4				
Sr			0.26	0.096	0.13	0.093				
Ti			0.013	0.003	0.017	0.002				
Tot P			0.15	0.02	0.03	0.02				
U			0.043	0.158	0.443					
V			0.004	0.001	0.001	0.001				
Zn			0.006	0.009	0.005	0.005				0.05
Zr			0.003	0.001	0.002	0.001				

ample for complete analysis.

les was "dissolved", "total" for all others.

er Quality Objectives (SSWQO) are displayed in bold lettering.

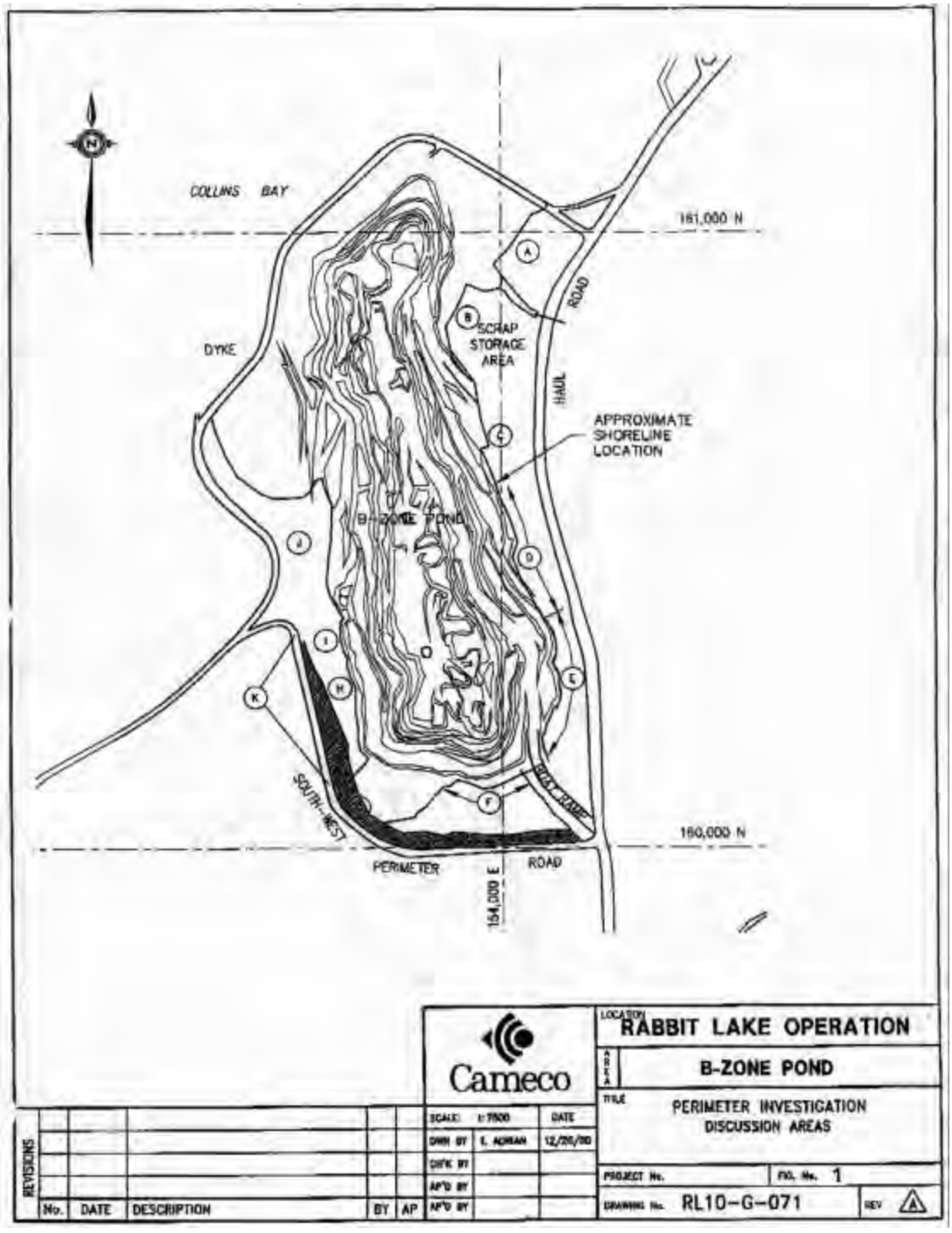


Figure 1: Perimeter Investigation Discussion Areas

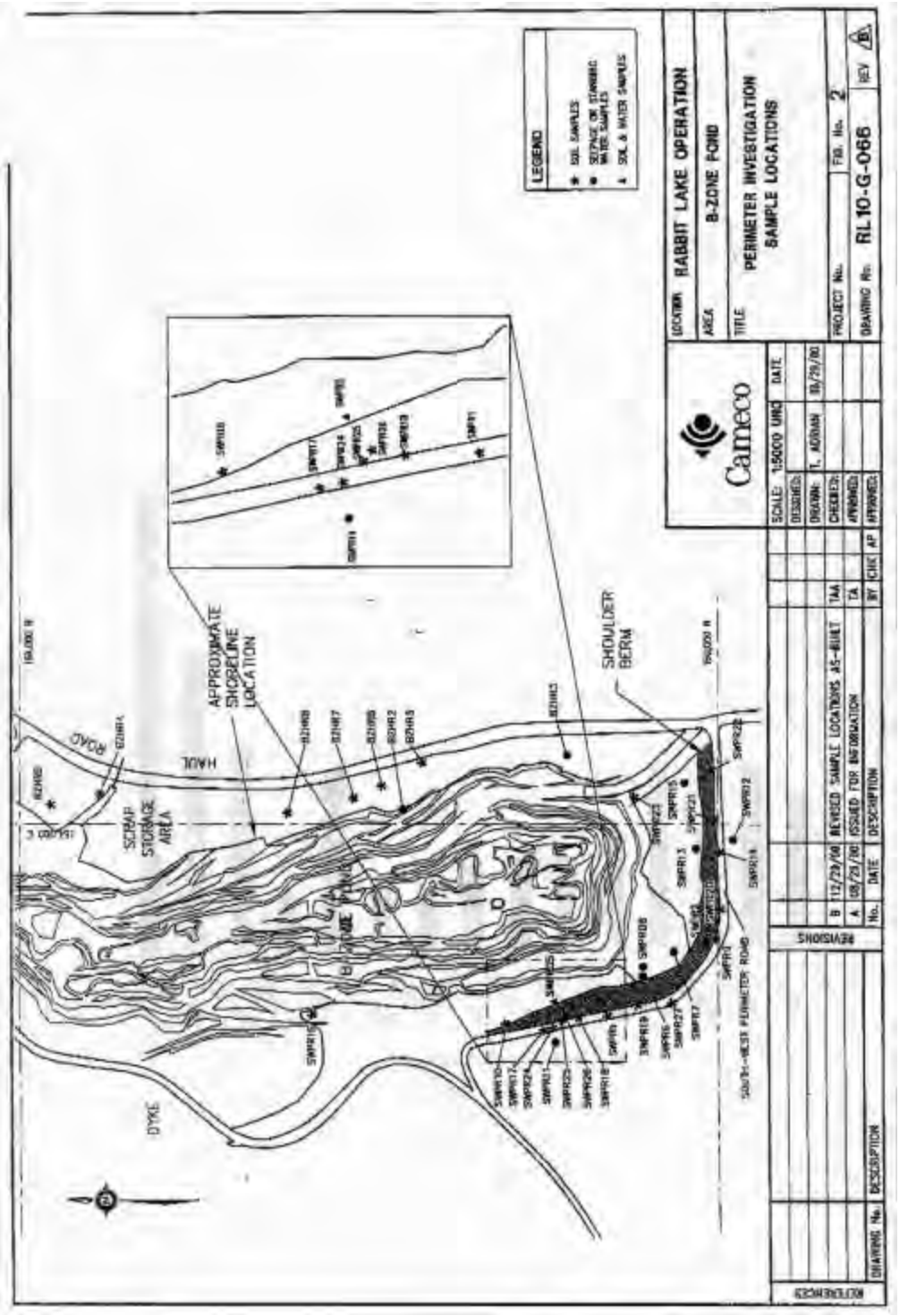


Figure 2: Perimeter Investigation Sample Locations

Photograph 1: Looking upstream toward a culvert under the haul road. Location: Area A, Figure 1.

Photograph 2: Shoreline erosion in silty soil. Location: Area B, Figure 1.

Photograph 3: Flow slide in soft till material. Location: Area C, Figure 1.

Photograph 4: Toppling block slope failure in waste rock. Location: D, Figure 1.

Photograph 5: Upslope location of Photograph 4, showing tension cracks and holes extending several meters behind the slope scarp. Location: Area D, Figure 1

Photograph 6: Close of view material in area D (Figure 1), which is toppling into the pond. Mineralized/altered material is present in the centre of the photograph

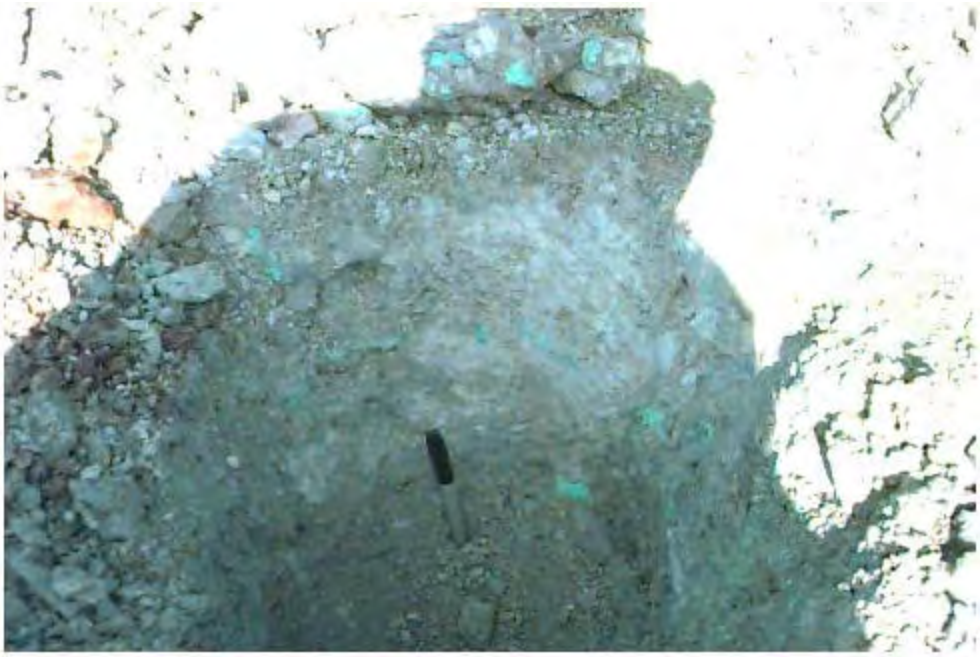
Photograph 7: View of shoreline in Area C (Figure 1), showing eroded beach and small seepage steam entering pond.

Photograph 8: View of erosion scarp on west side of Area G.

Photograph 9: Slope failure (mass wasting) in natural soil/peat materials in Area H.

Photograph 10: Alluvial fan extending from perimeter road toward B-Zone pond in Area 1.

Photograph 11: Looking south along southwest perimeter road in Area K (Figure 1). Note intense blue/green coloration in the foreground.



Photograph 12: Close-up of excavation at sample location SWPR1, showing abundance of "Blue Nuggets". (Pen for scale at photo centre.)

APPENDIX 1

BACKGROUND DATA

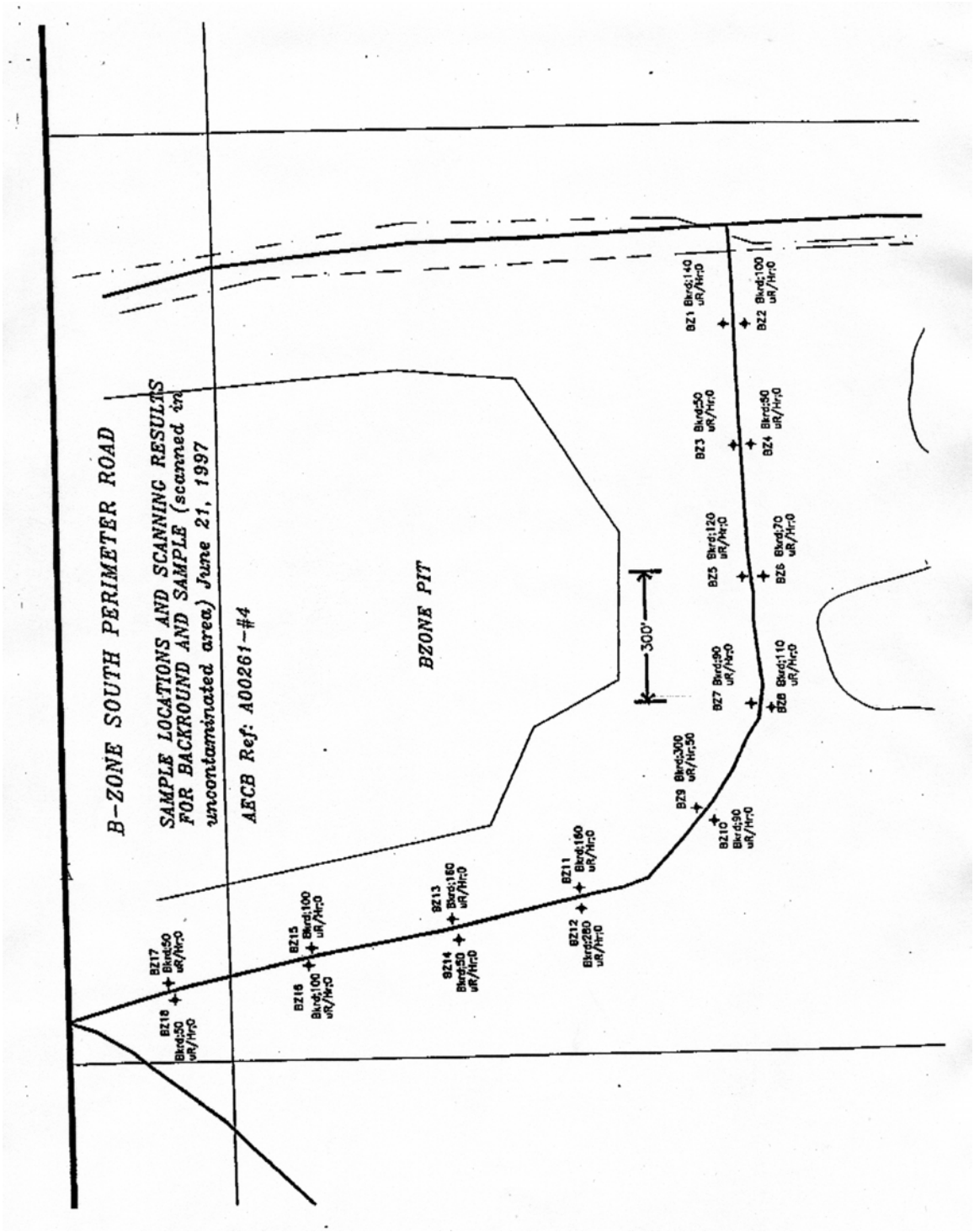

B-ZONE SOUTH PERIMETER ROAD
SAMPLE LOCATIONS AND SCANNING RESULTS FOR BACKROUND AND SAMPLE (scanned in uncontaminated area) June 21, 1997
AECB Ref: A00261-#4
BZONE PIT
300'
BZ1 Bkrd:140 uR/Hr:0
BZ2 Bkrd:100 uR/Hr:0
BZ3 Bkrd:50 uR/Hr:0
BZ4 Bkrd:50 uR/Hr:0
BZ5 Bkrd:120 uR/Hr:0
BZ6 Bkrd:70 uR/Hr:0
BZ7 Bkrd:90 uR/Hr:0
BZ8 Bkrd:110 uR/Hr:0
BZ9 Bkrd:300 uR/Hr:50
BZ10 Bkrd:90 uR/Hr:0
BZ11 Bkrd:160 uR/Hr:0
BZ12 Bkrd:260 uR/Hr:0
BZ13 Bkrd:160 uR/Hr:0
BZ14 Bkrd:50 uR/Hr:0
BZ15 Bkrd:100 uR/Hr:0
BZ16 Bkrd:100 uR/Hr:0
BZ17 Bkrd:50 uR/Hr:0
BZ18 Bkrd:50 uR/Hr:0

Table 1: Results of analyses of B-zone southwest perimeter road surface samples

Sample Name	Date Sampled	As µg/g	Ni µg/g	S µg/g	U µg/g
BZ1	22-Jun-97	138	168	210	610
BZ2	22-Jun-97	226	246	720	1,050
BZ3	22-Jun-97	135	87	340	340
BZ4	22-Jun-97	160	99	370	300
BZ5	22-Jun-97	545	410	180	1,090
BZ6	22-Jun-97	166	82	410	330
BZ7	22-Jun-97	208	517	520	390
BZ8	22-Jun-97	268	229	139	460
BZ9	22-Jun-97	480	396	1,300	810
BZ10	22-Jun-97	264	173	310	190
BZ11	22-Jun-97	3,250	1,649	290	620
BZ12	22-Jun-97	7,067	7,322	850	610
BZ13	22-Jun-97	1,046	527	320	330
BZ14	22-Jun-97	10,807	4,746	290	220
BZ15	22-Jun-97	596	356	440	350
BZ16	22-Jun-97	809	420	230	440
BZ17	22-Jun-97	348	171	200	420
BZ18	22-Jun-97	157	104	200	220
Min		135	82	139	190
Max		10,807	7,322	1,300	1,090
Mean		1,482	983	407	488

Table 5: Summary of Data by Key Rock Type

Summary Parameter	Field paste pH	Field conduct.	PASTE pH	S(T) %	AP	NP	NET NP	NP/AP	As	Ca	Co	Fe	Mg	Ni	Pb	U	Zn
Chloride Gneiss and Pegmatite																	
mean	6.83	97	7.74	0.019	0.52	3.4	2.87	6.6	5.7	2503	4.9	7745	8535	30	10	10	52
max	7.40	142	8.12	0.025	0.78	5.63	5.08		11.5	6315	11	14400	15870	43	12	20	84
min	6.20	66	7.51	0.01	0.16	0.11	-0.1		1	500	1.5	3342	3205	14	6.5	0	16
sd	0.49	32	0.21	0.007	0.3	1.98	1.92		4	2089	4	3932	4265	10	2	9	26
count	3	3	5	5	5	5	5		5	5	5	5	5	5	5	5	5
Graphitic Gneiss																	
mean	6.58	129	7.215	0.058	1.79	2.14	0.35	1.2	112	1132	8	8864	10198	341	25	454	40
max	7.60	233	8.23	0.151	4.72	3.7	2.41		490	2300	23	19300	18100	1481	80	2160	75
min	5.40	45	5.44	0.013	0.41	0	-4.7		2	500	2	3619	600	19	0	0	14
sd	0.82	82	0.95	0.056	1.72	1.24	2.59		190	616	8	5418	6067	571	28	854	28
count	4	4	5	5	5	5	5		5	5	5	5	5	5	5	5	5
Quartzite and Sandstone																	
mean	5.75	136	5.6	0.034	1.05	0.41	-0.63	0.4	479	400	6	3900	1900	362.5	17	355	15
max	5.80	140	6.07	0.037	1.16	0.46	-0.48		676	400	8	3900	2300	464	24	510	18
min	5.70	131	5.13	0.03	0.94	0.37	-0.79		282	400	4	3900	1500	261	10	200	12
sd	0.05	5	0.47	0.003	0.11	0.04	0.15		197	0	2	0	400	101.5	7	155	3
count	2	2	2	2	2	2	2		2	2	2	2	2	2	2	2	2
Sand and Sandstone																	
mean	6.33	113	7.12	0.019	0.56	0.87	0.31	1.6	34	503	2	6099	1930	29	12	74.545	35.272
max	7.20	282	7.72	0.063	1.97	2.76	1.29		166	1200	5	12400	10900	117	27	290	128.5
min	5.10	32	6.77	0.01	0.16	0	-0.29		4	300	1	2182	190	4	6	0	8
sd	0.56	73	0.23	0.016	0.47	0.76	0.45		37	265	1	2728	2949	32	6	85.212	33.992
count	9	9	11	11	11	11	11		11	11	11	11	11	11	11	11	11
Hematitic Sandstone																	
mean	6.29	74	6.92	0.016	0.46	0.61	0.13	1.3	73	418	3	15853	898	26	24	249	42
max	6.80	164	7.47	0.023	0.72	1.19	0.66		234	600	6	23100	2100	65	46	850	102
min	5.50	34	6.23	0.008	0.16	0	-0.51		20	100	1	10627	200	6	4	0	6
sd	0.38	39	0.37	0.005	0.18	0.39	0.37		64	180	2	4572	684	22	13	257	36
count	7	7	8	8	8	8	8		8	8	8	8	8	8	8	8	8
Till																	
mean	5.32	58							57	1540	3	13980	3480	34	8	48	32
max	6.30	116							236	1800	4	28200	4300	92	14	160	42
min	4.70	8							0	1300	2	8900	3000	10	2	0	18
sd	0.57	36							90	185	1	7155	475	30	4	57	9
count	5	5							5	5	5	5	5	5	5	5	5

APPENDIX 2

TEST OF PIT LOGS

TEST PIT: SWPR24
Project No: RAM P1182
Project: B-zone Perimeter Road Investigation
Location: Rabbit Lake B-zone Pond

Datum: Geodetic
Elevation: 405.83
Northing: 160,238.2
Easting: 153,697

Cameco Corporation
2121 11th St. West
Saskatoon, Sk.

Depth	Elevation	Description	Symbol	SAMPLE Number	SAMPLE Type	Comments
0	405.8	Ground Surface				
		Waste Rock Altered, blue				Samples collected in the test pit walls by scraping with track hoe bucket.
1				SWPR24A	G	
	404.5	**Till** Sandy, brown		SWPR24B	G	
2	403.5	End of Log				
3						

Excavation Method: Track Hoe
Date: September 16, 2000

Logged By: Ewan Yeates
Checked By: PGL
Sheet:

TEST PIT: SWPR25
Project No: RAM P1182
Project: B-zone Perimeter Road Investigation
Location: Rabbit Lake B-zone Pond

Datum: Geodetic
Elevation: 405.834
Northing: 160,225.6
Easting: 153,709.7

Cameco Corporation
2121 11th St. West
Saskatoon, Sk.

Depth	Elevation	Description	Symbol	SAMPLE Number	SAMPLE Type	Comments
0	405.8	Ground Surface				
		Waste Rock Altered, blue				Samples collected in the test pit walls by scraping with track hoe bucket.
1				SWPR25A	G	
	404.5					
		Till Sandy, brown		SWPR25B	G	
2	403.7					
		End of Log				
3						

Excavation Method: Track Hoe
Date: September 16, 2000

Logged By: Ewan Yeates
Checked By: PGL
Sheet:

TEST PIT: SWPR26A
Project No: RAM P1182
Project: B-zone Perimeter Road Investigation
Location: Rabbit Lake B-zone Pond

Datum: Geodetic
Elevation: 405.83
Northing: 160,221.37
Easting: 153,716

Cameco Corporation
2121 11th St. West
Saskatoon, Sk.

Depth	Elevation	Description	Symbol	SAMPLE Number	SAMPLE Type	Comments
0	405.8	Ground Surface				
		Waste Rock Altered, blue				Sample collected in the test pit walls by scraping with track hoe bucket. This pit was excavated at the boundary of the contaminated road. The A part (this log) was within the road, while the B part was in the shoulder material.
1				SWPR26A	G	
	404.3	**Till/Sandstone** Sandy, brown				
	404.0	End of Log				
2						
3						

Excavation Method: Track Hoe
Date: September 16, 2000

Logged By: Ewan Yeates
Checked By: PGL
Sheet:

TEST PIT: SWPR26B
Project No: RAM P1182
Project: B-zone Perimeter Road Investigation
Location: Rabbit Lake B-zone Pond

Datum: Geodetic
Elevation: 405.83
Northing: 160,221.37
Easting: 153,716

Cameco Corporation
2121 11th St. West
Saskatoon, Sk.

Depth	Elevation	Description	Symbol	SAMPLE Number	SAMPLE Type	Comments
0	405.8	Ground Surface				
		Till/Sandstone Sandy, brown				Sample collected in the test pit walls by scraping with track hoe bucket. This pit was excavated at the boundary of the contaminated road. The A part was within the road, while the B part (this log) was in the shoulder material.
1				SWPR26B	G	
	404.0	End of Log				
2						
3						

Excavation Method: Track Hoe
Date: September 16, 2000

Logged By: Ewan Yeates
Checked By: PGL
Sheet:

TEST PIT: SWPR27
Project No: RAM P1182
Project: B-zone Perimeter Road Investigation
Location: Rabbit Lake B-zone Pond

Datum: Geodetic
Elevation: 405.93
Northing: 160,065.6
Easting: 153,732.9

Cameco Corporation
2121 11th St. West
Saskatoon, Sk.

Depth	Elevation	Description	Symbol	SAMPLE Number	SAMPLE Type	Comments
0	405.8	Ground Surface				
		Till/Sandstone Sandy, brown				Sample collected in the bottom of the test pit by scraping with track hoe bucket.
1				SWPR27	G	
	404.6	End of Log				
2						
3						

Excavation Method: Track Hoe
Date: September 16, 2000

Logged By: Ewan Yeates
Checked By: PGL
Sheet:

B-ZONE PERIMETER ROAD 2001 FOLLOW-UP INVESTIGATION

CAMECO

2001

TABLE OF CONTENTS

LIST OF TABLES & FIGURES

1 INTRODUCTION

This report is a follow-up to investigations conducted on the B-zone Pond perimeter road in 2000.

On June 6, 2001, Pat Landine of Cameco performed a visual inspection of the B-zone perimeter as a follow-up to investigations conducted in 2000. Two areas were covered, the southwest perimeter road from the junction of the main haul road to the B-zone shop road and the east bank of the B-zone pond.

A second visual inspection was conducted on July 26, 2001. The purpose of this inspection was to select locations for test pits in the road and shoulder berm to collect samples for analysis of Ni and As. Portions of the west and east perimeter of the pond were also inspected.

2 SOUTHWEST PERIMETER ROAD

The following observations were made:

- In the first 70 m westward from the main haul road there was no indication of blue crusting on the road or shoulders of the road. (See Drawing RL10-G-072 for reference.) Beyond 70 m there was noticeable blue crusting on the shoulder of the road nearest to the pond. This blue crusting stretched all along the shoulder berm on the road to a point just south of the B-zone Shop Road junction with the perimeter road.
- The apparent thickness/colour density of the blue crust was variable, generally becoming thicker along the west side of the pond.
- It was noted that along desiccation cracks the evaporite crust appeared reddish brown in colour. This was in contrast to the general blue colour over most of the surface.
- Two samples of the evaporite crust were collected. BZ-ES1 was collected from predominantly blue crust while BZ-ES2 was collected from brown crust along desiccation cracks.
- No blue crusting was observed along the outside (bog side) of the road.

- Particularly in the July 26 inspection, it was observed that wherever the road was blue/green in colour, the adjoining bog area contained dead vegetation or was in poor health. Where the road was brown, the adjacent bog appeared to be healthy.

3 EAST BANK JUNE 6, 2001/JULY 26, 2001

A walking reconnaissance of the east bank of the B-zone pond from the location of 2000 sample BZHR 5 to BZHR 8 was also conducted. The following observations were made.

- The rate of mass wasting appears to be less than previously estimated (B-zone Pond Perimeter – Investigation of Ni Contamination. April 2001). The water depth offshore in most of this area is not great. In two areas of active mass wasting each about 20 m long the water near shore was deep (bottom was not visible).
- One small area of blue crusting was observed on the upper bank of the area in the approximate location of BZHR 5. The material in this area appeared to be waste rock; (i.e. the rock was sharp and angular). Some rock showed rapid weathering signs.
- An area of blue crusting was observed near the north end of the scrap steel lay-down area on July 26, 2001.

Although these areas show some degree of Ni contamination, they are much less of a concern than the southwest perimeter road area. In order to maximize the benefit for this year, our excavation efforts will be concentrated entirely on the southwest perimeter road.

4 ORTHWEST APPROACH TO B-ZONE DYKE

During the July 26 inspection, it was observed that a small area (about 20 m x 5 m) along the shore of the pond in the northwest corner of the pond had no vegetation (location indicated by letter A on Drawing RL10-G-072). Closer inspection revealed the presence of some blue crusting on the soil surface and small particles of blue material in the shallow subsurface.

This material will most likely be removed at some time; however, as stated above, the priority in 2001 is on the southwest perimeter road. The removal of this material has been proposed in the budget for 2002.

5 RUN-OFF TEST JUNE 7, 2001

A runoff collection test was conducted in a small catchment on the shoulder berm near sample location SWPR2 on June 7, 2001. The blue crusting in this area was typical of that in most areas of the road, in terms of crust thickness (colour density). A collection pail was dug into the ground at the downstream end of the area and water was poured over the slope.

- The catchment area was about 5 m long x 0.4 m wide at the downstream end and 1.5 m wide at the upstream end.
- About 30 L of water was poured on the area. The volume collected was about 3 L. Water was observed to disappear readily into cracks along the flowpath.
- The water sample was filtered through a 3 micron filter, preserved and sent to SRC for analysis. (Sample BZ-EW1). After filtering, the water sample was a bright green colour, with a pH of 4 and conductivity of 8,700 µS/cm.

6 TEST PITS IN SHOULDER BERM JULY 28, 2001

Three test pits were excavated in the shoulder berm material along the southwest perimeter road. The approximate locations of the pits are shown on Drawing RL10-G-072 (attached). Three soil samples were collected from each test pit as indicated on the test pit logs (attached).

7 RESULTS AND DISCUSSION

7.1 POSTULATED MECHANISM FOR FORMATION OF BLUE CRUST

The blue crusting appears to be the result of evaporative concentration of porewater, which is most evident during prolonged dry periods. (The Rabbit Lake site had experienced an extended dry period prior to these investigations.). It is theorized that rainwater falling on the road dissolves weathered Ni-As minerals in the road. The groundwater then flows horizontally to the sides of the road. Material in the shoulder berm on the pond side of the road is fine textured, while on the outside (bog side) of the road the texture is coarse. During a dry period, evaporation from the fine-textured material pulls water from a considerable depth due to capillary action, resulting in the build-up of an evaporite crust. In coarse material on the roadbed and outside shoulder, evaporation is limited by de-saturation of the coarse material. Everywhere that a blue-crust was observed, the material was fine-textured.

7.2 Chemical Analyses

7.2.1 Surface Crust and Run-off Water Samples

The surface crust samples and water sample were analyzed for a suite of elements. The results are listed in Table 1 for soil and Table 2 for water.

Sample BZ-ES1 consisting primarily of the blue crust material contained 31,900 µg/g nickel, and 460 µg/g arsenic. As a comparison, the nickel and arsenic concentrations of source rock material in the road (Sample SWPR19, collected in 2000) was about 16,000 µg/g for each element. Other metal concentrations were also elevated in the evaporite crust. Considering that the source minerals from which these elements were derived contained As and Ni in a 1:1 mass ratio, these results suggest that some mechanism is retarding the transport of As but not Ni. Given the mechanism of crust formation discussed above, it appears that As is being sorbed by the fine textured soils along the flowpath, while Ni is not subject to sorption. The brownish crust material typified by BZ-ES2 had somewhat lower concentrations of all metals.

The runoff water contained very high concentrations of nickel and sulphate, as listed in Table 2, indicating the presence of nickel sulphate salts in the evaporite crust.

7.2.2 Shoulder Berm Test Pit Samples

The results of Ni and As analyses for the test pit samples are shown in Table 3. Test Pit 1 shows somewhat elevated concentrations of As and Ni throughout the full depth. Test pit 2 has very low levels of As and Ni at depth, in contrast to Test Pit 3 where the upper and mid depth samples are clean and the deepest zone shows higher levels of Ni and As. The relatively high concentration of As at the bottom of Test Pit 1 may be due to sorption of As from percolating fluid originating in the contaminated roadbed material.

Although this soil has concentrations of Ni and As that are above background, there is no evidence that this presents a risk, particularly in the case of more deeply buried soils. Therefore we do not propose to remove the shoulder berm at this time.

It should be remembered that this general area was host to an ore body that contained elevated levels of Ni and As; therefore, it may be unrealistic to apply background standards of mineralization to any clean-up exercise.

7.2 Approximate Loading Calculation

The amount of Ni washed into the B-zone Pond by a light rain occurring after a dry spell may be estimated to within an order-of-magnitude based on the runoff test results, as outlined below.

- The volume of water applied was 30 L, which is equivalent to about 6 mm of rain over the test area of 5 m^2.
- The area subject to blue crusting, which may contribute runoff was estimated to be 8,000 m^2, based on field observations and measurements from aerial photographs (1995).
- Based on the 10% runoff factor observed in the test, the volume of water entering the pit by surface flow from a 6 mm rainfall event would be 4.8 m^3.
- Using the Ni concentration observed in the field test (2310 mg/L), the mass of Ni entering the pit from this rain event would be about 11 kg.
- The nickel concentration in the B-zone Pond would rise by 0.002 mg/L due to this event.

The increase in Ni concentration is small compared to the observed seasonal fluctuations in Ni concentration. However, it should be noted that in a larger rainfall event, the runoff factor would increase substantially. Albeit, the concentration of nickel would likely be inversely proportional to the volume of rain, at least during a high intensity event. The quantity of groundwater flow originating in the Ni source rock would also increase. It is quite probable that, on a seasonal basis the quantity of Ni entering the pond from this road could exceed 100 kg, enough to have a measurable effect on the overall Ni balance for the B-zone Pond.

8 SUMMARY

The results of this investigation lend stronger impetus to the need for removal of nickel-rich waste rock from the southwest perimeter area. Previously, (B-zone Pond Perimeter Investigation of Ni Contamination, April 2001), it was indicated that removal of the contaminated road material could possibly have a positive impact on B-zone Pond water quality. It now appears that removal of the contaminated material offers the potential to have a greater positive impact than originally expected. It is still not known if this action will measurably reduce the nickel levels in the ponded water. It also appears that the contaminated road material might have had a negative impact on the adjoining bog. Consequently, removal of the road material may begin to reverse this apparent impact.

9 ACTIONS

The road bed material is to be removed over the full width of the road extending from the B-zone Shop Road junction to a point about 70 m from the main haul road. Spoil material from the excavation is to be hauled to the B-zone Ore Pad, most likely for later use as backfill at Eagle Point. The depth and lateral extent of excavation is to be determined by visual observations. Soil testing under the supervision of an experienced field technician (Ewan Yeates) will be carried out to provide documentation of the work. Soil samples will be sent to SRC for determination of Ni and As.

Previously proposed activities for 2001 (slope stabilization and excavation) along the east bank of the pond will be delayed and are currently proposed for next year's budget, as the quantity of Ni entering the pond in this area is much smaller than along the southwest perimeter road.

The area subject to excavation/remediation this year will be checked in 2002 and 2003 for any new signs of nickel bloom.

It is expected that the shoulder berm may continue to show some tendency for nickel bloom in the 2 or 3 years following clean up. If the intensity of the bloom does not decrease, further measures will be undertaken to address other sources of nickel..

Table 1: Soil chemistry analysis of surface crust material collected on June 6, 2001 from the B-zone southwest perimeter road shoulder berm.

Analyte	Units	[1] BZ-ES1	[2] BZ-ES2
Ag-W	mg/L	0.001	0
Al-W	mg/L	28	0
As-W	**µg/L**	**420**	**0**
Ba-W	mg/L	0.091	0
Be-W	mg/L	0.032	0
B-W	mg/L	0.15	0
Ca-W	mg/L	460	0
Cd-W	mg/L	0.001	0
Cl-W	mg/L	13	0
CO3-W	mg/L	1	0
Co-W	mg/L	73	0
Cr-W	mg/L	0.013	0
Cu-W	mg/L	5.7	0
Fe-W	mg/L	2.4	0
HCO3-W	mg/L	6	0
K-W	mg/L	230	0
Mg-W	mg/L	610	0
Mn-W	**mg/L**	**200**	**0**
Mo-W	mg/L	0.014	0
Na-W	mg/L	45	0
Ni-W	mg/L	2310	0
OH-W	mg/L	1	0
Pb-W	mg/L	0.51	0
pH-W	units	4.55	0
Si-W-sol	mg/L	3.1	0
SO4-W	mg/L	8400	0
Sr-W	mg/L	4.3	0

[1] BZ-ES1 blue crust material

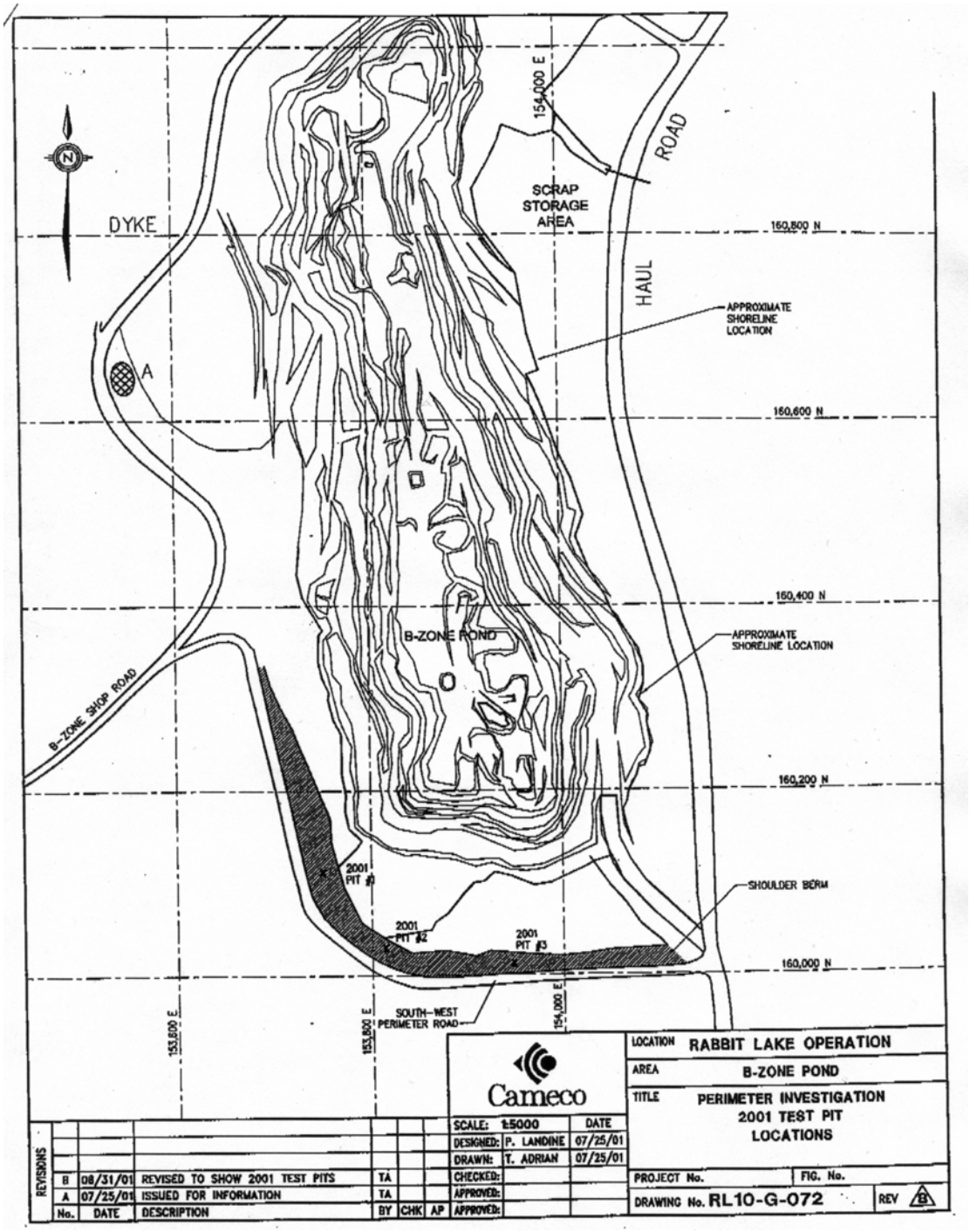
[2] BZ-ES2 brownish crust material

Table 2: Water chemistry analysis of runoff collected on June 6, 2001 from B-zone perimeter road shoulder berm.

Analyte	Units	Result
Ag-W	mg/L	0.001
Al-W	mg/L	28
As-W	**µg/L**	**420**
Ba-W	mg/L	0.091
Be-W	mg/L	0.032
B-W	mg/L	0.15
Ca-W	mg/L	460
Cd-W	mg/L	0.001
Cl-W	mg/L	13
CO3-W	mg/L	1
Co-W	mg/L	73
Cr-W	mg/L	0.013
Cu-W	mg/L	5.7
Fe-W	mg/L	2.4
HCO3-W	mg/L	6
K-W	mg/L	230
Mg-W	mg/L	610
Mn-W	mg/L	200
Mo-W	mg/L	0.014
Na-W	mg/L	45
Ni-W	**mg/L**	**2310**
OH-W	mg/L	1
Pb-W	mg/L	0.51
pH-W	units	4.55
Si-W-sol	mg/L	3.1
SO4-W	**mg/L**	**8400**
Sr-W	mg/L	4.3
TALK-W	mg/L	5
Ti-W	mg/L	0.006
Tot P-W	mg/L	0.18
U-W	µg/L	7500
V-W	mg/L	0.005
Zn-W	mg/L	11
Zr-W	mg/L	0.017

Table 3: Chemical analysis results for Test Pit Samples.

2001 Test Pit Number	Sample Number	As ug/g	Ni ug/g
Test Pit 1	GC-121	410	380
	GC-122	610	590
	GC-123	1200	730
Test Pit 2	GC-124	390	340
	GC-125	150	100
	GC-126	1.5	5.1
Test Pit 3	GC-127	20	12
	GC-128	13	13
	GC-129	890	350


DYKE
SCRAP STORAGE AREA
154,000 E
ROAD
HAUL
160,800 N
APPROXIMATE SHORELINE LOCATION
A
160,600 N
160,400 N
B-ZONE POND
APPROXIMATE SHORELINE LOCATION
B-ZONE SHOP ROAD
160,200 N
2001 PIT #1
2001 PIT #2
2001 PIT #3
SHOULDER BERM
160,000 N
153,600 E
153,800 E
SOUTH-WEST PERIMETER ROAD
154,000 E
Cameco
LOCATION RABBIT LAKE OPERATION
AREA B-ZONE POND
TITLE PERIMETER INVESTIGATION 2001 TEST PIT LOCATIONS
SCALE: 1:5000
DESIGNED: P. LANDINE 07/25/01
DRAWN: T. ADRIAN 07/25/01
CHECKED:
APPROVED:
PROJECT No.
FIG. No.
DRAWING No. RL10-G-072
REV B
REVISIONS
B 08/31/01 REVISED TO SHOW 2001 TEST PITS TA
A 07/25/01 ISSUED FOR INFORMATION TA
No. DATE DESCRIPTION BY CHK AP

TEST PIT: 2001 Test Pit 1
Project No: RAM Q1067
Project: B-zone Perimeter Road Removal
Location: Rabbit Lake B-zone Pond

Datum: Geodetic
Elevation: 406
Northing: 160,112
Easting: 153,750

Cameco Corporation
2121 11th St. West
Saskatoon, Sk.

Depth	Elevation	Description	Symbol	SAMPLE Number	SAMPLE Type	Comments
0	406.0	Ground Surface				
		Till Tan, some clay and silt		GC-121	G	Samples collected in the test pit walls by scraping with track hoe bucket. The was no indication of waste rock (sharp angular stones), the pebbles, cobbles and boulders were rounded. No oxidation and breakdown to clay minerals was seen.
1				GC-122	G	
2				GC-123	G	
	403.5	**Organics** Orignal ground surface. Excavation did not extend beyond the top of this layer.				
3	403.0					

Excavation Method: Track Hoe
Date: July 28, 2001

Logged By: Ewan Yeates
Checked By: PGL
Sheet:

TEST PIT: 2001 Test Pit 2
Project No: RAM Q1067
Project: B-zone Perimeter Road Removal
Location: Rabbit Lake B-zone Pond

Datum: Geodetic
Elevation: 406
Northing: 160,030
Easting: 153,814

Cameco Corporation
2121 11th St. West
Saskatoon, Sk.

Depth	Elevation	Description	Symbol	SAMPLE Number	SAMPLE Type	Comments
0	406.0	Ground Surface				
		Till "Ablation Till" tan, silty clay litel sand		GC-124	G	Samples collected in the test pit walls by scraping with track hoe bucket.
1				GC-125	G	The was no indication of waste rock (sharp angular stones), the pebbles, cobbles and boulders were rounded. No oxidation and breakdown to clay minerals was seen.
	404.3	**Till** "Basal Till". grey clay till		GC-126	G	
2	404.0					
	403.9	**Organics** Roots, stumps and peat. The excavation was stopped at the top of this layer. Thickness of organic layer is not known.				
		End of Log				
3						

Excavation Method: Track Hoe
Date: July 28, 2001

Logged By: Ewan Yeates
Checked By: PGL
Sheet:

TEST PIT: 2001 Test Pit 3
Project No: RAM Q1067
Project: B-zone Perimeter Road Removal
Location: Rabbit Lake B-zone Pond

Datum: Geodetic
Elevation: 406
Northing: 160,012
Easting: 153,948

Cameco Corporation
2121 11th St. West
Saskatoon, Sk.

Depth	Elevation	Description	Symbol	SAMPLE Number	SAMPLE Type	Comments
0	406.0	Ground Surface				
		Till Tan, silty, some sand		GC-127	G	Samples collected in the test pit walls by scraping with track hoe bucket. The was no indication of waste rock (sharp angular stones), the pebbles, cobbles and boulders were rounded. No oxidation and breakdown to clay minerals was seen.
	405.2					
1		**Till** Olive, silty , some sand		GC-128	G	
2	403.4					
		Till Grey, clayey, some sand, some organics mixed in.		GC-129	G	
3	403.0					

Excavation Method: Track Hoe
Date: July 28, 2001

Logged By: Ewan Yeates
Checked By: PGL
Sheet:

App5-Table 1a: Water Chemistry for B-Zone Pit S-W Perimeter Road Surface Samples

Date Sampled	Sampling Location	Sample Type	Depth of Stratum	pH	Cond $uS.cm^{-1}$	Temp. (C)	Flow (mL/min)	As $mg.L^{-1}$	Ni $mg.L^{-1}$	S $mg.L^{-1}$	Fe $mg.L^{-1}$	U $mg.L^{-1}$	^{226}Ra $Bq.L^{-1}$
20-Jun-99	SWPR-1	Filtered Slurry Supernatant	0-0.1 cm	5.2	11920	25		1.72	1,530				
20-Jun-99	SWPR-1		0.1 - 1 cm	5.1	2880	25		0.72	240				
23-Jun-99	BZSEEP3	R/O Event into Pit						0.46	26	260	0.061	0.14	7.8
23-Jun-99	BZSEEP3	R/O Event Puddle						0.86	9.1	130	0.082	0.23	3.8
23-Jun-99	BZSEEP3	Road R/O Event Puddle						0.34	44	320	0.79	0.17	6.5
31-Aug-99	SWPR-7 =BZSEEP 1	Seepage to Pit		5.7	145	9	230	0.58	2.84			0.562	0.719
31-Aug-99	SWPR-8 =BZSEEP 2	Seepage to Pit		5.8	151	9	230	0.31	3.12			0.223	0.224
23-Aug-00	BZHR-3	Pond Water			133	23.8							
23-Aug-00	BZHR-4	Seepage Water			228	16.5							
19-Aug-00	SWPR-3							1.14	0.197				
19-Aug-00	SWPR-4		10-90 cm					0.65	0.077				
19-Aug-00	SWPR-5		40-65 cm					0.26	3.342				
19-Aug-00	SWPR-7	seepage-BZPit subaerial seepage					300	0.036	0.166				
19-Aug-00	SWPR-8	seepage					300	0.07	0.153				
24-Aug-00	SWPR-11	Pool Water			265	18.3							
24-Aug-00	SWPR-12	Wetland Pond			163	19.6							
24-Aug-00	SWPR-13				250	19.1							
24-Aug-00	SWPR-15				125	19.2							

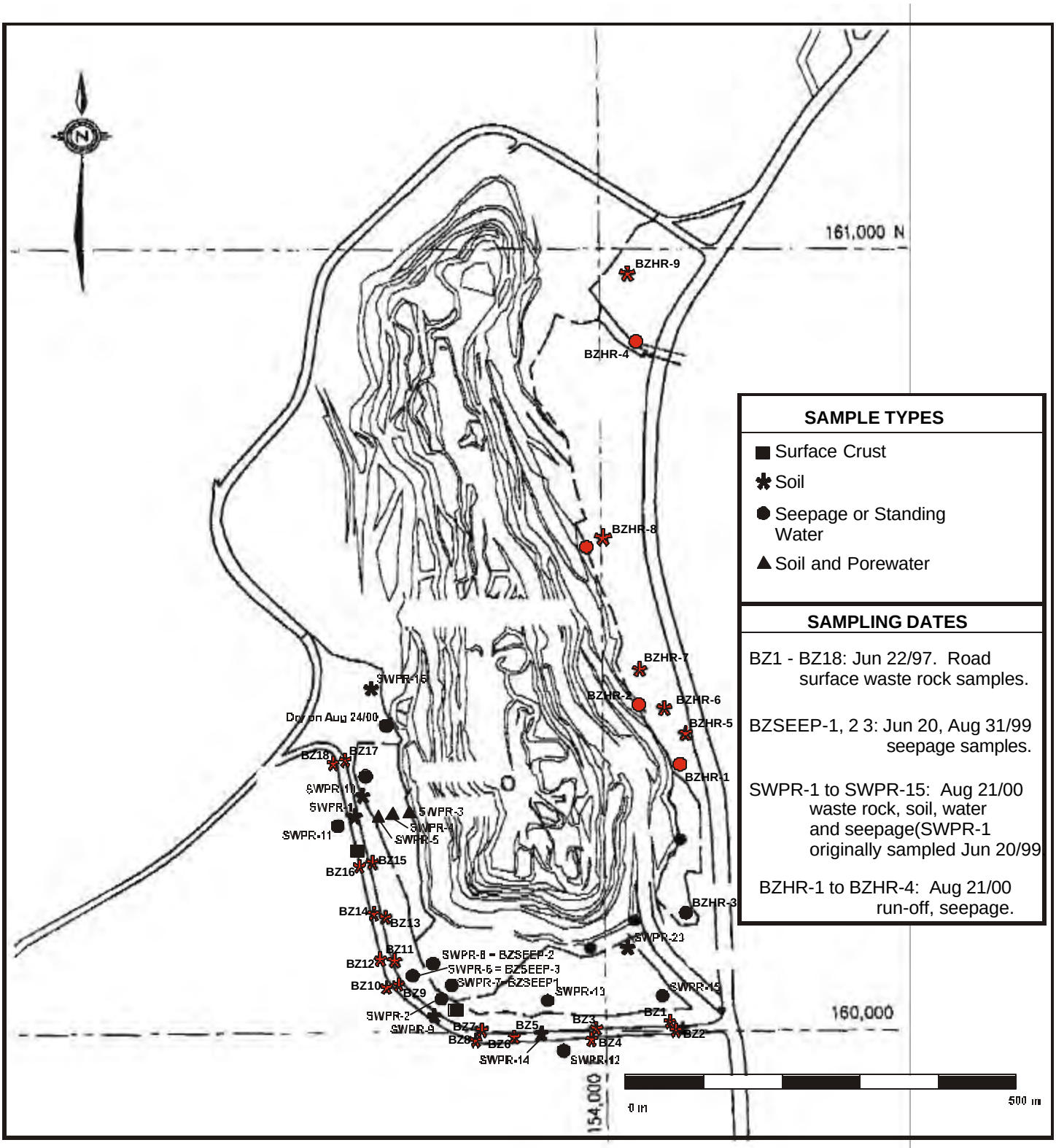
Filtered Slurry Supernatant '* 10 g of dried sample slurried with 100 mL of distilled de-ionized water for 1 minute. Solids allowed to settle.

Supernatant filtered through 0.45 um filter.

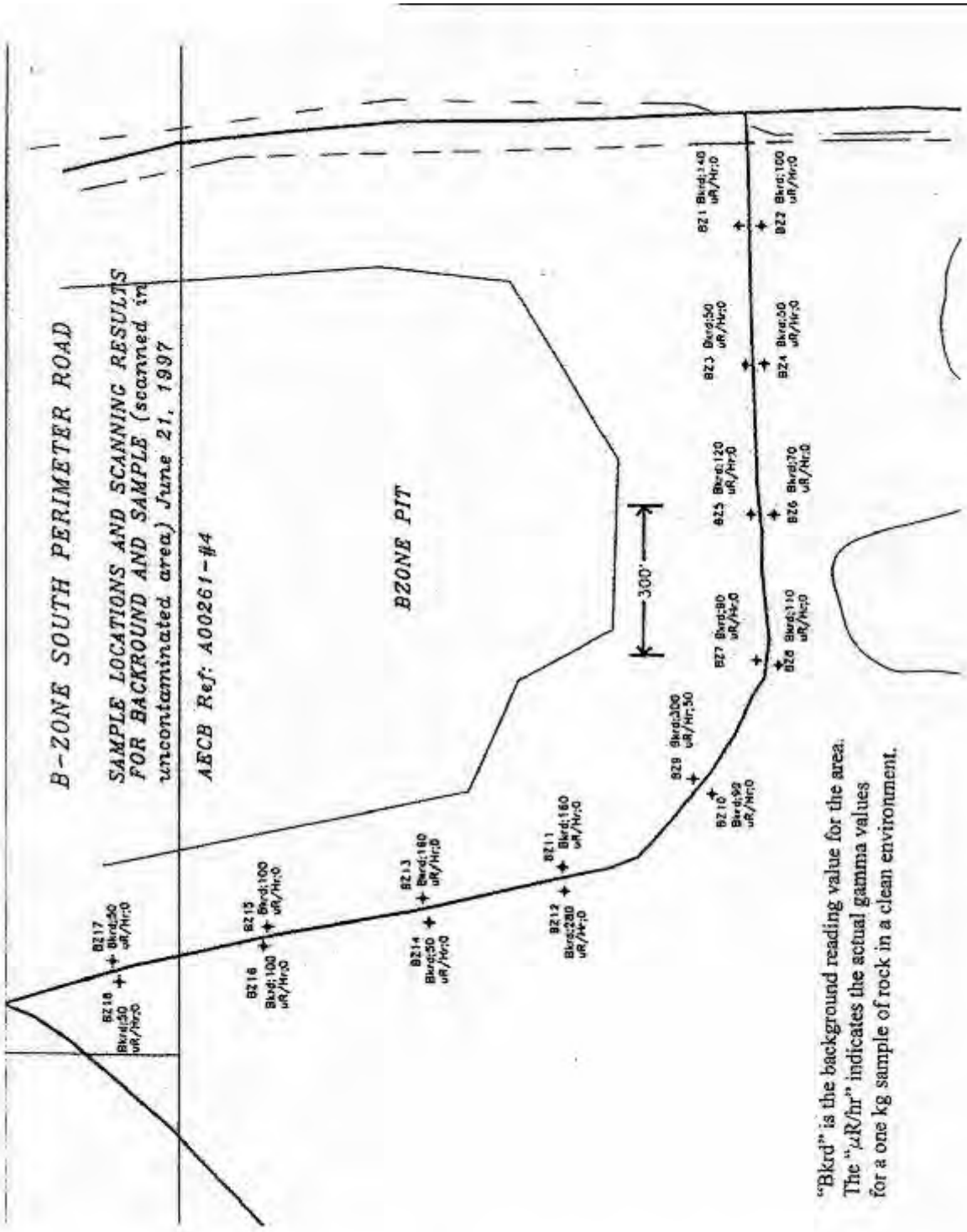
App 5-Table 1b: As, Ni, S and U of Solids in Road Bed Waste Rock, B-Zone Waste Rock Pile and Road Bed Evaporite

1993 (B-Zone WRP Drilling), 1997 (M. Baldero, Cameco) and 1999 (Boojum)

Sampling Location	Sample Type	Date sampled		As	Ni	S	U
				$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$
BZ 1 - BZ 18	Road Bed Waste Rock	1997	N	18	18	18	18
			min	135	82	139	190
			max	10,807	7,322	1,300	1,090
			average	1,482	983	407	488
B-Zone (Table 11, 1996 report)	Waste Rock Pile	1993	min	1	6	200	5
			max	2,760	1,800	4,600	539
			average	**69**	**90**	**302**	**69**
			N	97	97	97	97
SWPR-1	Road Bed Evaporite	20-Jun-99	0-0.1 cm	140	14,700	not availble	
SWPR-1			0.1 - 1 cm	70	2,700		
SWPR-1 Conc.	Road Bed Waste Rock	19-Aug-00	0-15 cm	2800	195000		
SWPR-1 Bulk				<100	5000		



Map 1: Blue Road Overview of Sampling Stations



Map of B-Zone Pit Southwest Perimeter Road Bed Waste Rock Sampling Locations
(M.Baldero, Cameco, June, 1997)

Development of a Flooded Uranium Pit over 10 Years and Fate of Contaminants

Margarete Kalin Boojum Research Limited 139 Amelia St., Toronto Ontario, Canada M4X 1E6 Tel: 416-861-1086 e-mail: margarete.kalin@utoronto.ca

1991 Prior to Flooding

Introduction

The B-Zone pit uranium mine, is part of Cameco Corporation's Rabbit Lake Operation in northern Saskatchewan, Canada.

The 5 million m^3 B-Zone pit lake (Plate 1,2) provides a unique opportunity to identify processes controlling water quality in a newly formed pit lake and indicate how water quality improvements may be enhanced, e.g. by increasing primary productivity. This pit lake has been intensively studied over the period 1992 to 2001 (Kalin et al., 2000, 2001)

- *After force flooding of the pit in the winter of 1991-1992, elevated As, Ni and suspended solids (TSS) concentrations were observed.*
- *However, within a year, reductions in these and other parameters in the pit lake water were noted and have since continued to decline.*
- *No amendments were added to the pit so changes observed represent the early, natural development of a new pit lake.*

References

Kalin, M., M.P. Smith and Y. Cao, (2000) "Sedimentation in a pit lake in relation to water quality changes" Proceedings of the International Symposium on the Process Metallurgy of Uranium, Uranium 2000, Saskatoon, Saskatchewan, September 9-15, pp. 613-630.

Kalin, M., C. Cao, M.P. Smith and M.M. Olaveson, (2001) Development of the Phytoplankton Community in a Pit-Lake in relation to Water Quality Changes", Water Research (35:13) pp. 3215-3225.

Results and Conclusions

The pit lake is a closed system, with no external sources. Changes in chemistry from 1993 to 2001 are shown in Table 1. Reductions of As and Ni concentrations are controlled by:

- ***Thermal stratification*** *- summer thermocline in the upper waters and complete turn over by following spring.*
- ***Particulates*** *containing contaminants reach the sediment during winter.*
- ***Primary productivity*** *in pit through colonization by the mucilage -forming alga Dictyosphaerium sp. (Plate 3)*
- *Algal biomass/particulates accumulate above summer thermocline (Fig. 1, 2), reducing surface water Ni concentrations.*
- *Algal mucilage facilitated agglomeration of particles containing Fe, Ni and As.*
- *Sedimentation was quantified in sedimentation traps at 2, 12, 22 and 32 m (Plate 4)*
- *Summer-time reductions did not translate into substantial year to year Ni reductions (Fig. 3)*
- *An external Ni source has been identified to account for continued surface inputs to pit.*
- *Seasonal Ni pattern likely due to release from decomposing biomass near thermocline.*
- *[As] reductions associated with Fe particulates agglomerated with biomass and As settles to the lake bottom.*
- *As concentrations in the water column showed a substantial reduction from 1993 to 2001 (Fig. 4)*
- *The quantity of As found in the sediment agreed well with reduction in the water concentration (Table 2).*

Contaminants released into the B-Zone pit following flooding (e.g. Ni and As) were effectively sequestered in sediments within 10 years without amendments or other modifications

2001 Post Flooding

Table 1: Chemistry and concentration changes 1993-2001

Parameter	Mean Concentration (mg/L)		Decrease (-) / Increase (+)
	1993	2001	
$HCO3^-$	13.1	31.8	142%
Conductivity (µs/cm)	53.4	87.5	64%
Na	1.8	2.4	34%
Al	1	0.008	-99%
As	0.28	0.019	-93%
Cl	1.8	0.72	-59%
Fe	0.75	0.29	-61%
Ni	0.27	0.19	-31%
Ra^{226}-diss (Bq/L)	0.05	0.03	-47%
Ra^{226}-total (Bq/L)	0.143	0.018	-87%
U (total)	0.026	0.01	-62%

Table 2: Sedimentation Loads and Bottom Sediment Loads

Year	Sedimen. Rate g/m²/day	Per year g/m²	As Content g/m²	Ni Content g/m²	Fe Content g/m²	Al Content g/m²	PO_4 Content g/m²
1992	28.7	10472	1.5	1.7	184	161	24
1993	28.7	10472	3.8	4.7	99	77	22
1994	11.6	4227	7.9	4.5	60	38	8
1995	13.0	4758	12.8	3.4	62	30	9
1996	3.5	1285	2.7	0.9	26	18	2
1997	2.4	876	6.7	1.1	41	14	3
1998	2.6	931	4.0	0.9	44	17	2
1999	2.0	737	2.7	0.4	38	10	2
total		33757	42	18	555	366	73
IN SEDIMENT 1999 Depth 0-7 cm			30	17	566	619	57

Thanks to CAMECO for funding and the assistance of all at Boojum